

Current Design Practice of Flexible Debris-resisting Barriers

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- **Technical Development Works on Flexible Barriers by GEO**

Harris

- **Introduction of Flexible Barriers**

Eric

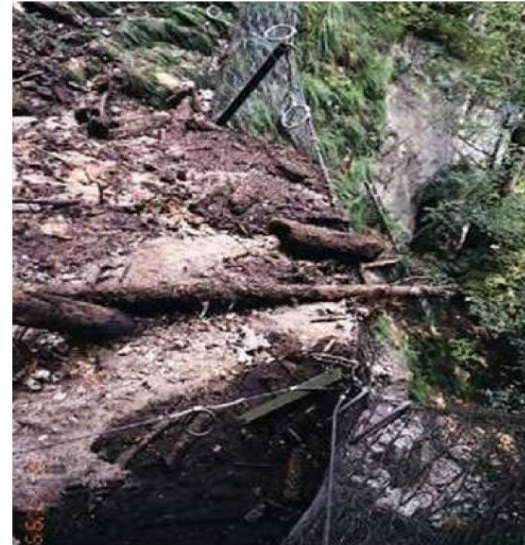
- **Current Local Design Practice**

Background (Global)

- Long history (>40 years) of using flexible barriers to resist rockfalls over the world. Occasionally, rockfall barriers were hit by landslide debris and able to stop/retain a certain amount of debris.
- Research of flexible barriers subject to debris impact has been emerging in the past decade. Internationally-recognized design guidelines are still limited.



1998: 750 m³ debris flow in Japan
(retained by 1500 kJ rockfall Barrier)



2000: 200 m³ debris flow in Austria
(retained by 750 kJ rockfall Barrier)

Background (Hong Kong)

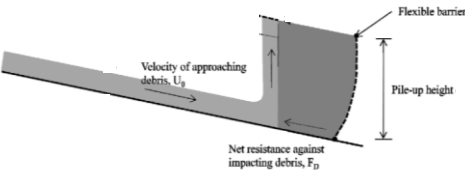
- Implementation of LPMitP since 2010 triggered a series of technical development work by GEO on design of flexible barrier to resist debris flows in Hong Kong.
- Improved understanding on performance of flexible barriers has been made in recent years, largely due to availability of more field impact data, experimental data and advanced numerical tools that can simulate complex, highly non-linear debris-barrier interaction.
- Focus was given to establishing Design Approaches, with the aid of advanced numerical tools, for the design of flexible barriers to resist landslide debris.

Overview of Development on Design Approaches

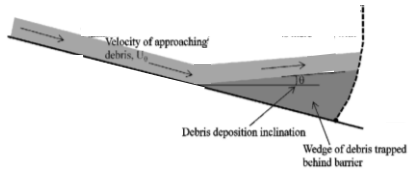
Stage 1 – Energy Approach (2010-2012)

Stage 2 – Force Approach (2012-2015)

Stage 3 – Coupled Analyses using LS-DYNA (2015-2018)



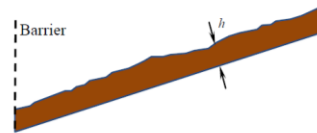
(a) Pile-up mechanism



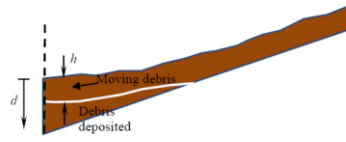
(b) Run-up mechanism



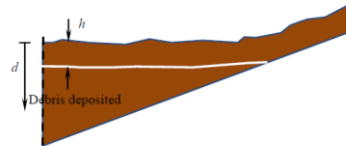
Flowing and Deposition Sequence of Debris



(i) Debris front reaches the barrier and deposition begins (first debris surge)



(ii) Debris climbs above deposited debris (subsequent debris surges)



(iii) Debris piles up behind the barrier (last debris surge filling up the barrier)

Loading on Barrier

$$p_d = \alpha \rho_d v^2$$

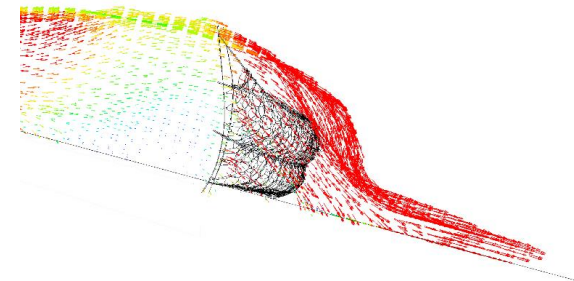
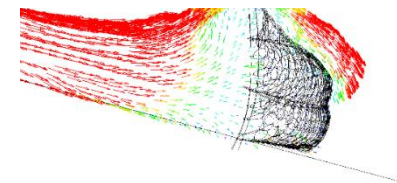
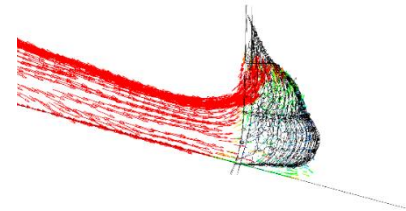
$$p_d = \alpha \rho_d v^2$$

$$p_s = K \rho_s g d$$

$$p_d = \alpha \rho_d v^2$$

$$p_s = K \rho_s g d$$

$$p_d = \alpha \rho_d v^2$$



Stage 1 - Develop Energy Approach (2010-2012)

Stage 2 - Develop Force Approach (2012-2015)

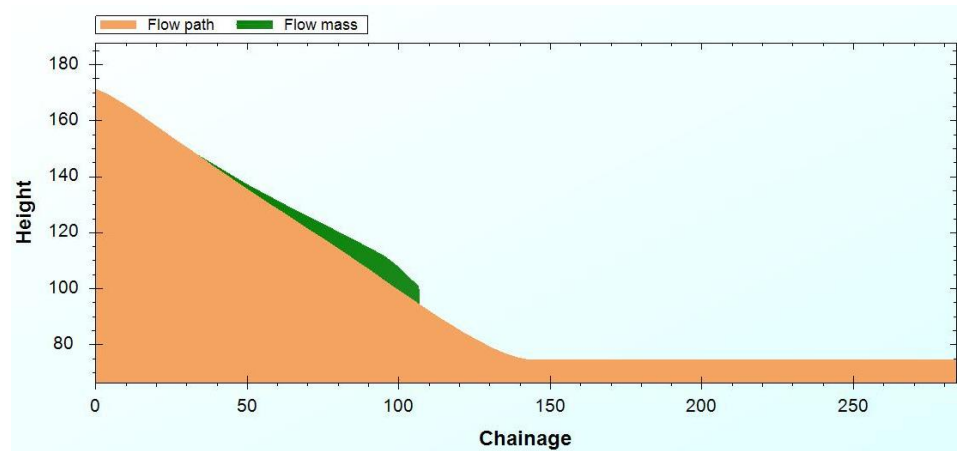
Stage 3 - Development of Coupled Analyses using LS-DYNA (2015-2018)

Further Work

Dynamic Load Model

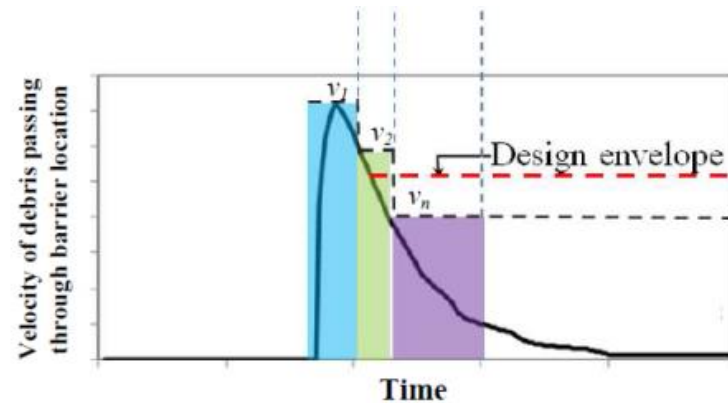
$$p_d = \alpha \rho_d v^2$$

- ρ_d = density of moving debris.
- v = velocity of moving debris hitting the barrier (m/s)
- α = dynamic pressure coefficient, taken to be 2.0



Refined Assessment of design impact velocity (c) (TGN 44)

observations of local landslide cases and physical flume test results suggest that debris velocity varies along the length of landslide debris



v_n = design impact velocity of the n^{th} phase \propto 0.7 maximum debris velocity of the hydrograph

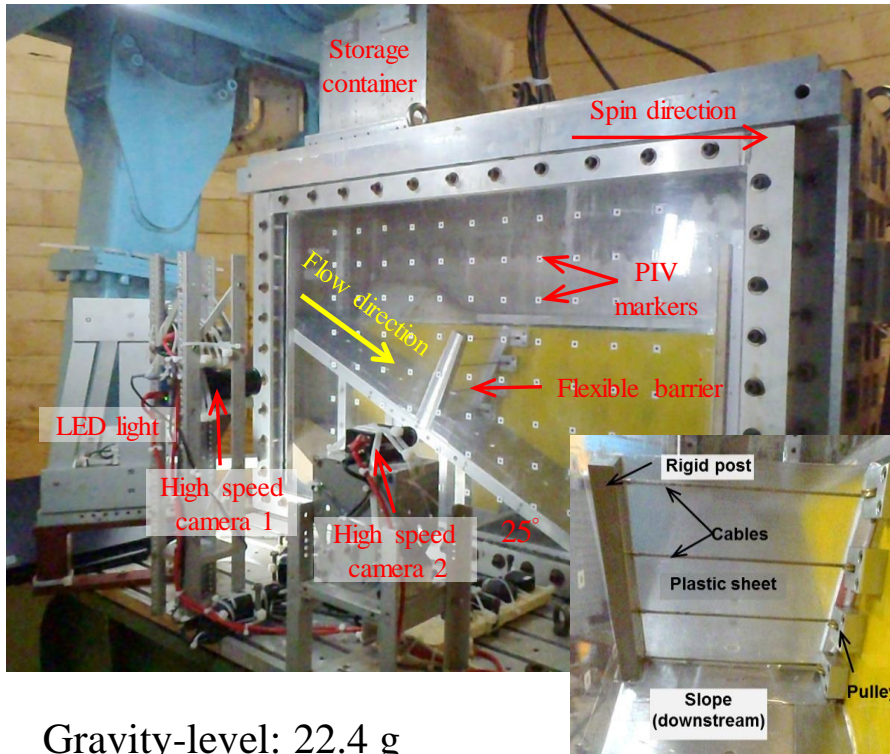
Stage 1 - Develop Energy Approach (2010-2012)

Stage 2 - Develop Force Approach (2012-2015)

Stage 3 - Development of Coupled Analyses using LS-DYNA (2015-2018)

Further Work

Centrifuge Tests to study dynamic pressure coeff. (α)



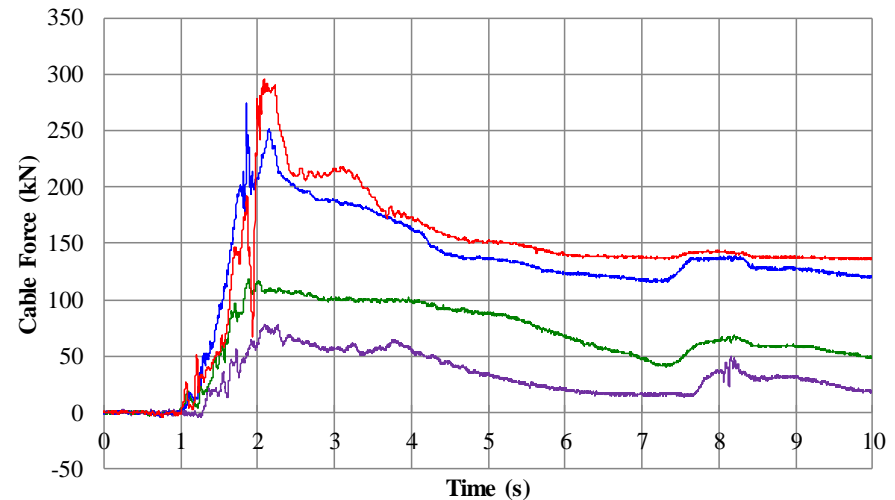
Gravity-level: 22.4 g
 Debris volume: 170 m³ (prototype)
 Debris velocity: 9 – 22 m/s
 Barrier height: 4.5 m (prototype)

Dynamic Load Model

$$p_d = \alpha \rho_d v^2$$

ρ_d = density of moving debris.
 v = velocity of moving debris hitting the barrier (m/s)
 α = dynamic pressure coefficient, taken to be 2.0

Cable Force-Time History (FSL20)



For two-phase material, $\alpha = 0.7 - 1.3$
 (Song et al, 2018)

Rockfall Barriers Commonly Used in Hong Kong to Resist Debris Flow at Drainage Lines



Is there any better structural form of flexible barriers (other than those post-supported) for incised drainage lines?

Structural Forms of Flexible Barriers

- **Post-supported barriers** are commonly used in Hong Kong



Open hillside

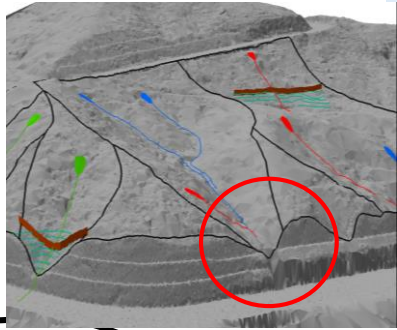


Drainage line

- Overseas project adopts **side-anchored barriers** in drainage lines

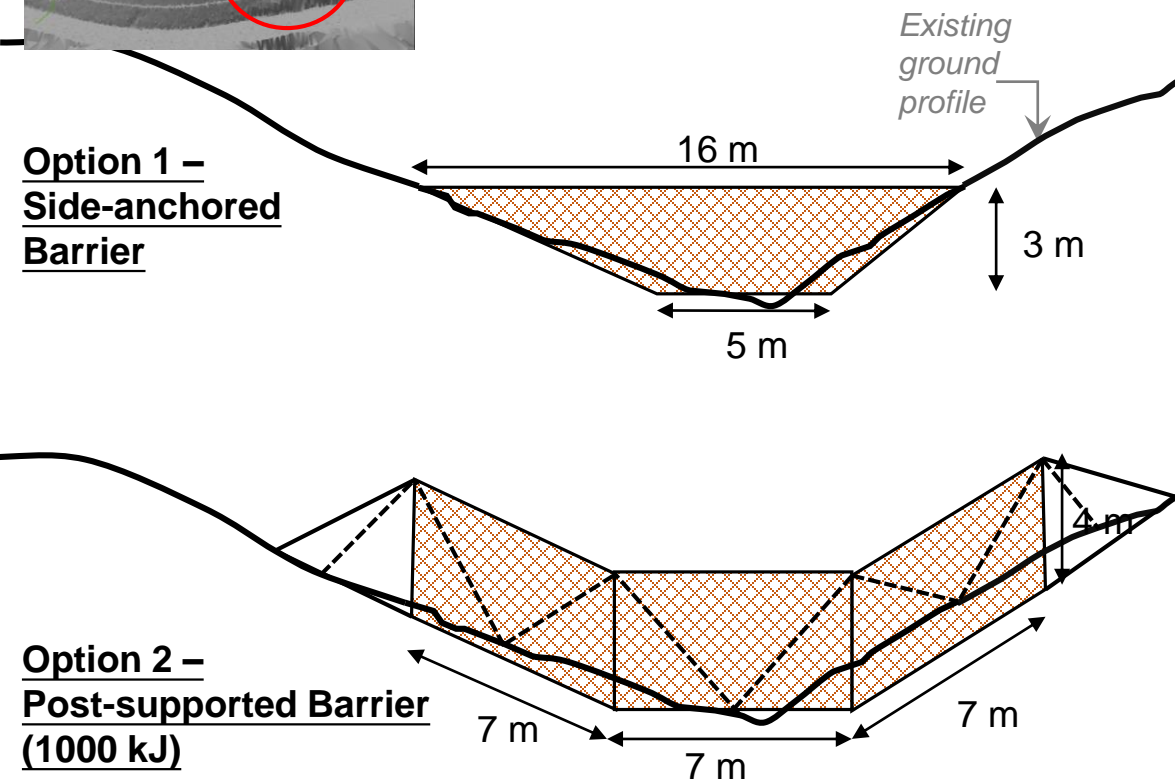


Comparison of Side-anchored barriers and post-supported barriers (for drainage line setting)



Flow thickness = 0.6 m
Debris impact velocity = 4 m/s
Debris impact energy = 534 kJ
Debris impact pressure = 70 kPa
Required retention volume = 100 m³

Design	Side-anchored Barrier (Option 1)	Post-supported Barrier (Option 2)
Principal Net area	30 m ³	80 m ³
Cable length	~80 m	> 200 m
Anchor points	8 nos.	15 nos.
Ease of installation	Simple (no heavy posts involved)	-
Maintenance	Lower (less materials used)	Higher (difficult access to upslope cables)
Environmental Impact	Less visual impact Less disturbance to environment	-



Structural Components and Load Path

Side-anchored Barriers



Simple internal load-transfer

net → cables & brakes → anchors

No posts or upslope cables required

Post-supported Barrier



More complex load-transfer

net → cables & brakes → anchors

↳ posts → upslope cables & brakes → anchors

Posts and upslope cables required

May be susceptible to direct debris impact



Yu Tung Road, Hong Kong (Jun 2008)



Localised damage of post (Trumer)

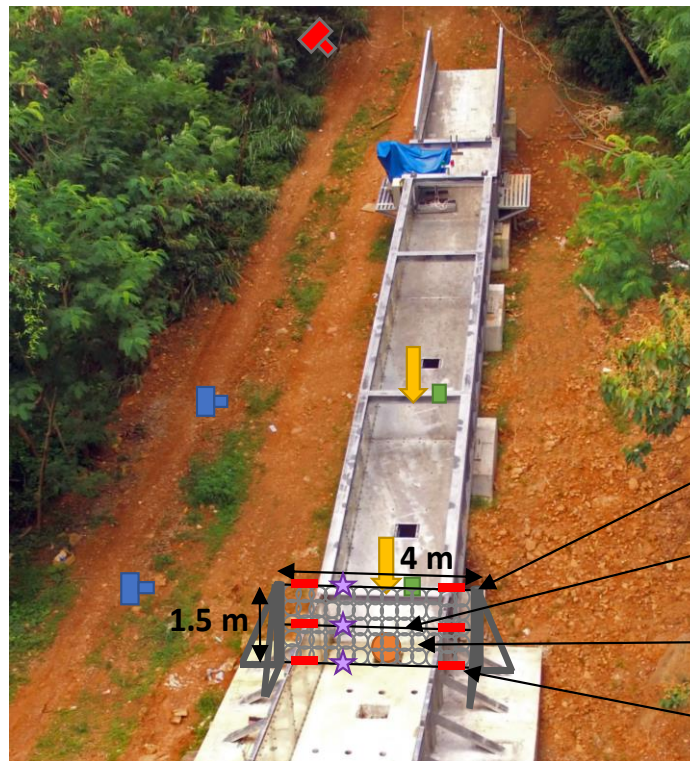
Test Plan to study Side-anchor Barriers in Hong Kong

(to be carried out in 2019)



Type 1 Barrier

- 0.8 m high x 2 m wide
- Test vol. 4 m³
- Test of overflow conditions



Type 2 Barrier

- 1.5 m high x 4 m wide
- Test vol. 10 m³

Legends:

- ↓ Laser sensors
- High-speed cameras
- ◆ Unmanned aerial vehicles
- Cameras
- Load cells
- ☆ Tension links

Steel frame to simulate steep side slope of a drainage line

Longitudinal support cables

Ring nets and secondary mesh

Brake elements

Improved Robustness of Post Supported barriers

Supporting post susceptible to localised damage due to boulder impact



Use of Baffles



Post Strengthening

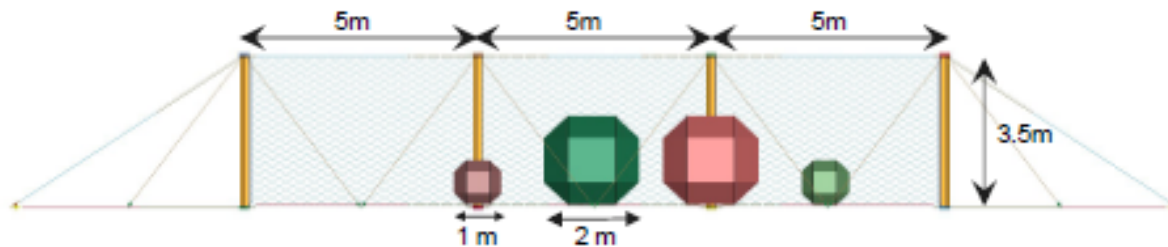


Fig. 40 Elevation of multi-boulders and the barrier model

One 2m size boulder is proposed to impact at the bottom-centre of the middle module of the barrier system. And another 2m size boulder is proposed to impact at the right-middle post. The two 1m size boulder are proposed to impact at the post and the centre of a module of barrier respectively.

Wind Effect on Post-supported Barriers

- Overturning of barrier could occur under significant wind load.



Detailing to prevent trapping of Stream load



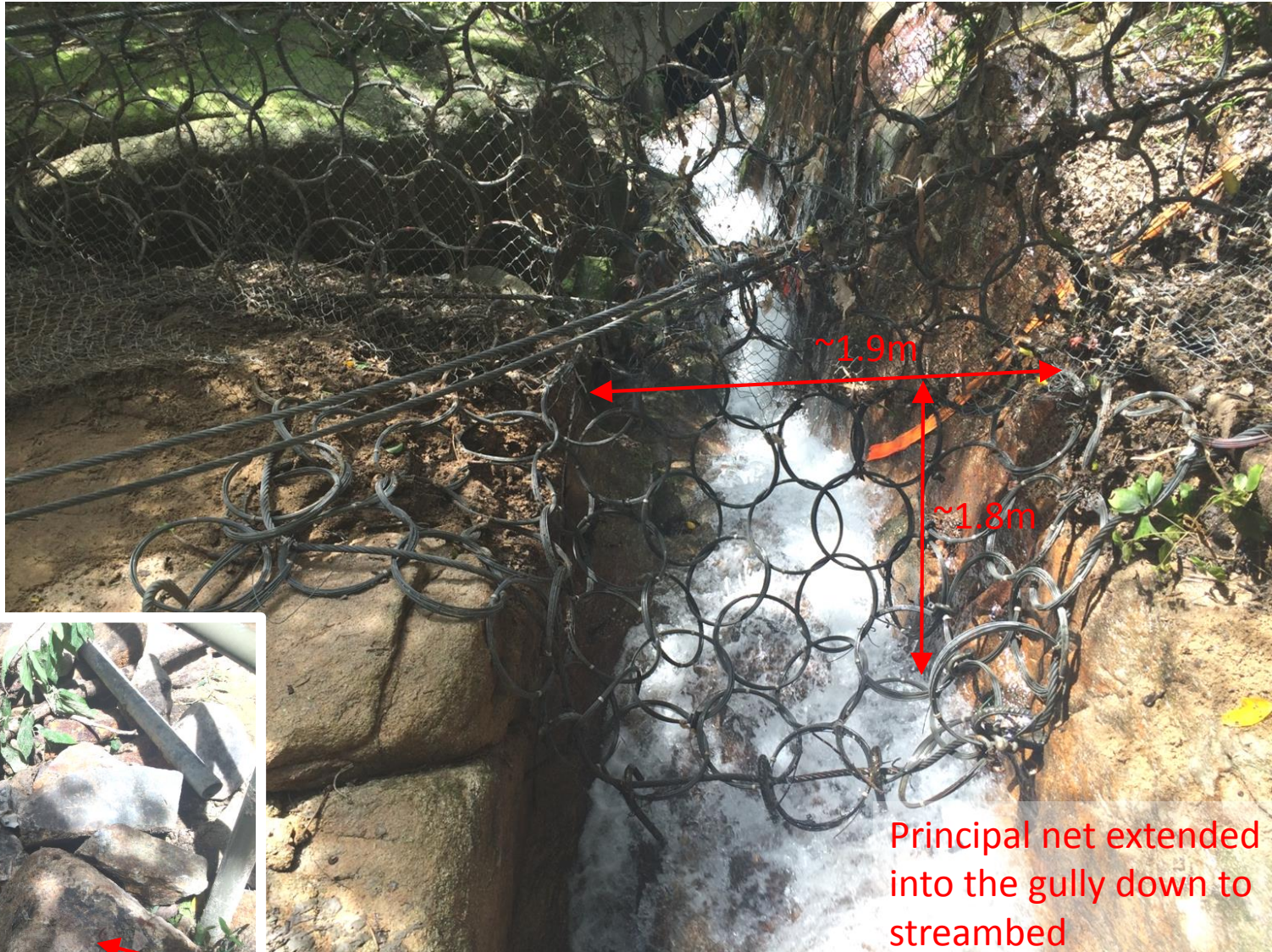
Year 2013 (Upon completion)



Year 2016 (after flooding)



Flexible Barrier above Shatin Hospital (July 2017 – Debris Removed approx. 10 m³)



Principal net extended into the gully down to streambed

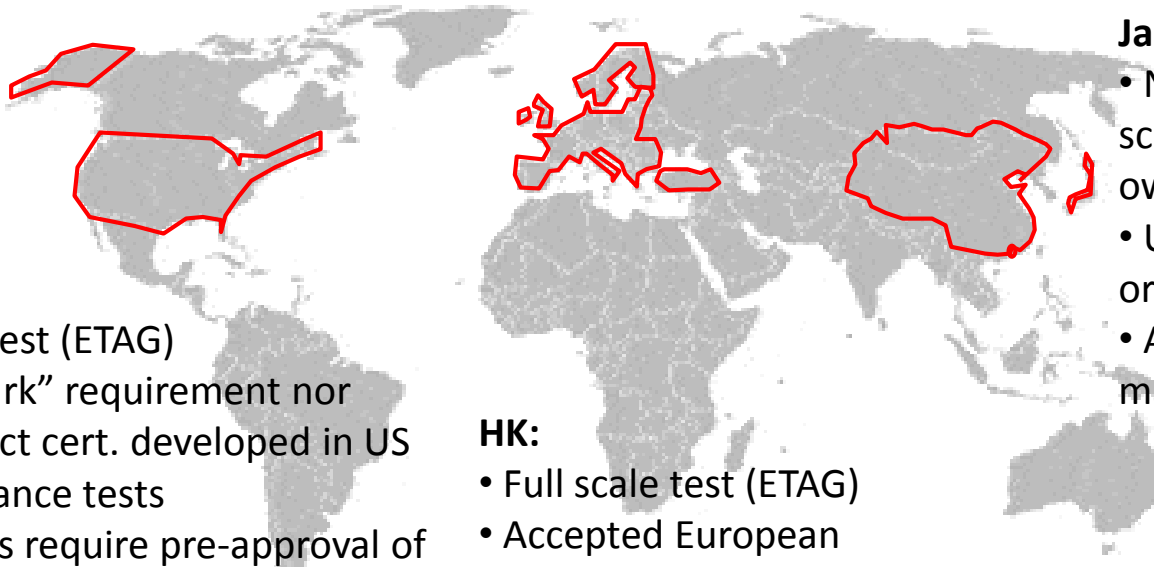


Bottom part of debris (~0.8m depth) comprised boulder-sized materials (~0.3 – 0.5m)

International Practice on Acceptance System

- 30+ countries in EU + Switzerland + Turkey :**
- Full-scale test (ETAG)
 - CE Mark
 - No compliance tests

- China:**
- Full scale test by NRA (similar to ETAG 27)
 - No CE Mark Requirement
 - No similar product cert in China
 - Component tests required in some projects



- Japan:**
- No national standard on full-scale test (each company use his own way to carry out tests)
 - Use locally-developed barriers or import barriers from Europe
 - Accept component with JIS marks

- HK:**
- Full scale test (ETAG)
 - Accepted European products mostly delivered to HK with CE Mark
 - **Compliance Tests required**

- New Zealand:**
- Full-scale test (ETAG)
 - CE Mark not mandatory
 - No compliance tests

- USA:**
- Full-scale test (ETAG)
 - No “CE Mark” requirement nor other product cert. developed in US
 - No compliance tests
 - Some states require pre-approval of suppliers (based on barrier’s design, specification, full scale test report, job reference, etc.)

- Remarks:
- No standard international practices on acceptance of barriers
 - ETAG is an internationally-recognized standard for full scale test.
 - “CE Mark” is the only available product certification system for flexible barriers in the world.
 - Other countries mainly import European barriers (with ETAG full-scale test proof) for local use, without compliance test (unlikely in HK).

European Practices - ETAG 27

Full Scale test



0 Front view of the falling rock protection barrier GBE-8000A after MEL test (29.11.2011).



1 Bottom view of the falling rock protection barrier GBE-8000A after MEL test.

Technical Assessment Body (TAB)

- Supervise and certify full scale test
- Assessment covers Barrier's Characteristics including **energy absorption, deformation, foundation loads, durability**, etc.
- Issue an evaluation report and ETA Certificate



Factory Production Control



Certification Body ("Notified Body")

- Initial type-test of product
- Initial factory inspection and production control
- Continuous surveillance (once a year), assessment and approval of factory production control



Example 1	
CE	Letters "CE"
XXXX	- Identification number of the notified body involved in the attestation of conformity (certification body)
04	- Name and address of the producer (legal entity responsible for the manufacturer)
XXXX CPD zzzz	- Last two digits of the year in which the CE marking was affixed
ETA-08/007	- Number of the EC certificate of conformity (consisting of number of notified body involved in the A/C, "year")
ETAG No XXXX	- CPD - number of EC certificate of conformity ("year")
YYY	- Number of the European Technical Approval
Energy level classification: 3	- ETAG number including date of publication
Residual height category for maximum energy level: A	- ETAG number including date of publication
	- Corresponds to the definition of the product (including the possibility to use the trade mark)
	- Class according to 2.4.3.2 in the ETAG
	- Category according to cl. 2.4.3.2 in the ETAG

Eidgenössische Materialprüfungs- und Forschungsanstalt

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EMPA

Mitglied der EOTA
Member of EOTA

BAUPRODUKTE

European Technical Approval **ETA - 12/0213**
Europäische Technische Zulassung

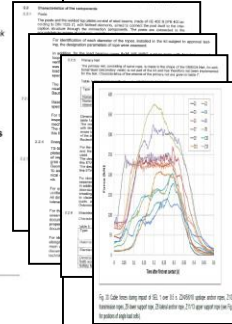
(English translation - Original version in German language)

Handelsbezeichnung Trade name	Steinschlagschutzsystem Falling Rock Protection Barrier RXE-8000
Zulassungsinhaber Holder of approval	Geobrugg AG Geohazard Solutions Aachstrasse 11 CH-8590 Romanshorn
Zulassungsgegenstand und Verwendungszweck	Steinschlag-Schutzsystem um sich bewegende Steinblöcke mit einer maximalen Energiestufe von 8000 kJ aufzuhalten.
Generic type and use of construction product	Falling rock protection barrier for use in civil engineering works to stop moving rock blocks with a maximum energy level of 8000 kJ.
Geltungsdauer Validity	vom from bis to 14.06.2013 13.06.2018
Herstellwerk Manufacturing plant	Geobrugg AG Geohazard Solutions Aachstrasse 11 CH-8590 Romanshorn

Diese ETA enthält
This ETA contains

31 Seiten einschliesslich Anhang (14 Seiten)
31 pages including annex (14 pages)

EOTA Europäische Organisation für Technische Zulassungen
European Organisation for Technical Approvals



TSLUS TECHNICKÝ A SKÚŠOBÝ ÚSTAV STAVEBNÝ, s. r. o.
BUDOVÁ 3, 821 04 Bratislava

EC CERTIFICATE OF CONFORMITY

1301 - CPD - 0915

In compliance with the Directive 89/106/EEC of the Council of European Communities of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to the construction products (Construction Products Directive - CPD), amended by the Directive 93/68/EEC of the Council of European Communities of 22 July 1993, it has been stated that the construction product

Falling Rock Protection Barrier RXE-8000
Energy level classification
8

Classification for residual height for MEL
Category A
with the intended use to stop moving rock blocks on a slope with the Service Energy Level > 1500 kJ and with the Maximum Energy Level > 4500 kJ and covers a range of ambient temperatures from - 20 °C to + 50 °C,

placed on the market by the manufacturer

Geobrugg AG
Geohazard Solutions
Aachstrasse 11, 8590 Romanshorn
Switzerland

and produced at the manufacturing plant
Geobrugg AG
Geohazard Solutions
Aachstrasse 11, 8590 Romanshorn
Switzerland

is submitted by the manufacturer to a factory production control and to the further testing of samples taken at the factory in accordance with a prescribed test plan and that the Notified body No. 1301 - Technický a skúšobný ústav stavebný, s. r. o. has performed the initial type-testing for the relevant characteristics of the product, the initial inspection of the factory and of the factory production control and performs the continuous surveillance, assessment and approval of the factory production control.

This certificate attests that all provisions concerning the attestation of conformity and the performances described in the
ETA - 12/0213
were applied and that the product fulfills all the prescribed requirements.

This certificate was first issued on 29 June 2013 and remains valid as long as the conditions laid down in the harmonised technical specification in references or the manufacturing conditions in the factory or the FPC itself are not modified significantly.

Bratislava, 28 June 2013



Dipl. Ing. Daria Kozlová
Head of Notified Body 1301

054566

Maintenance Strategy - Condition Review of Flexible Barriers

No Rusting

Bay no.	Post (m2)	Ground plate (nr)	Principal net (m2)	Anchor (nr)	Energy - dissipating device (nr)	Wire rope (m)	Shackle (nr)	Wire rope clip (nr)	Others Thimble (nr)
Bay 1	2	0	50	4	4	112	12	74	11
Bay 2	1	0	50	1	1	67	9	48	6
Bay 3	1	1	50	1	2	63	9	47	6
Bay 4	1	1	50	1	1	67	9	48	6
Bay 5	1	0	50	1	2	67	9	48	6
Bay 6	1	1	50	1	2	67	9	48	6
Bay 7	1	1	50	3	3	107	11	72	11
Subtotal	8	4	350	12	15	550	68	385	52
%	100%	50%	100%	100%	47%	99%	100%	99%	58%



Signs of Minor Rusting at brake element

Minor Rusting

Bay no.	Post (m2)	Ground plate (nr)	Principal net (m2)	Anchor (nr)	Energy - dissipating device (nr)	Wire rope (m)	Shackle (nr)	Wire rope clip (nr)	Others - Thimble (nr)
Bay 1	0	2	0	0	2	0	0	2	0
Bay 2	0	1	0	0	3	0	0	0	0
Bay 3	0	0	0	0	2	4	0	1	0
Bay 4	0	0	0	0	3	0	0	0	0
Bay 5	0	1	0	0	2	0	0	0	0
Bay 6	0	0	0	0	2	0	0	0	0
Bay 7	0	0	0	0	3	0	0	0	2
Subtotal	0	4	0	0	17	4	0	3	2
%	0%	50%	0%	0%	53%	1%	0%	1%	2%



Shackles

Overall Summary

- GEO would continue to carry out technical development work on the following, with a view to enhancing the design and maintenance standards of debris-resisting flexible barriers in Hong Kong.
 - Design approach
 - Structural form
 - Detailing
 - Acceptance Systems
 - Maintenance Strategy

Typical Design Flowchart for Natural Terrain Mitigation Measures



Open Hillslope Landslide



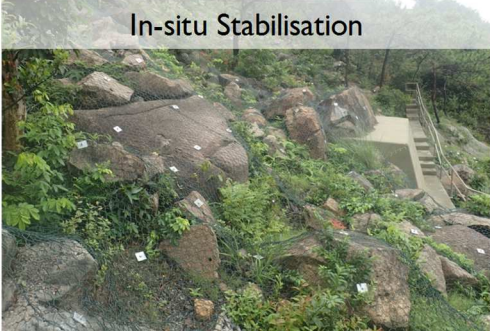
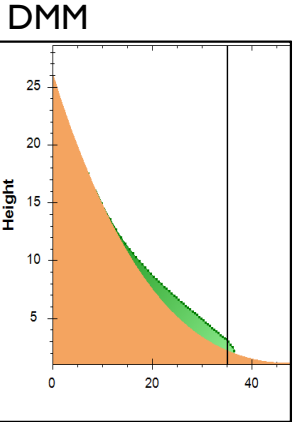
Deep-seated Failure



Debris Flow



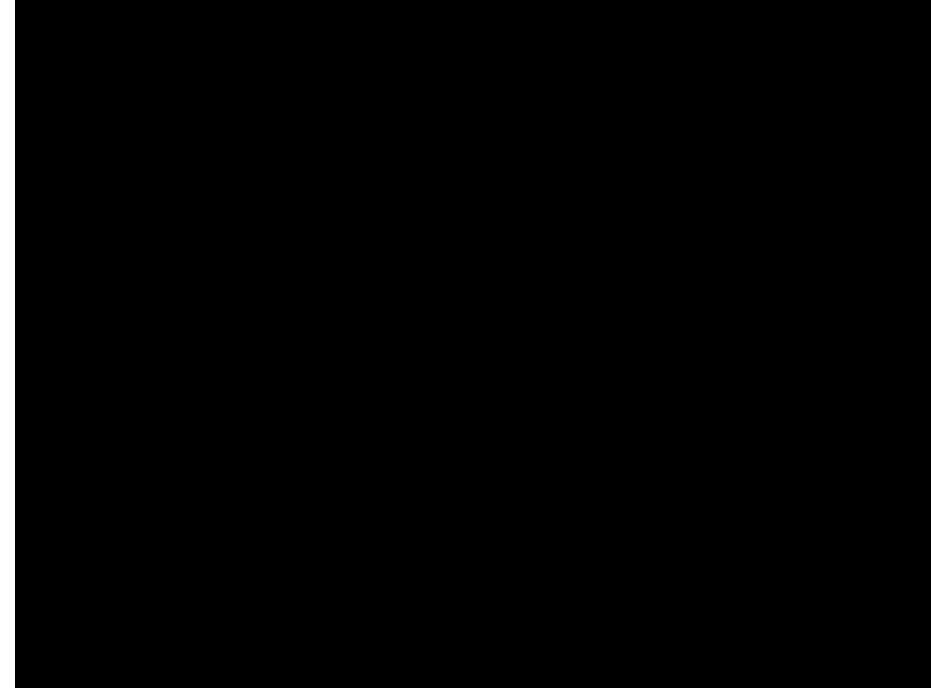
Rock / Boulder Fall



Working principle of flexible barriers



Source: Geobrugg, St Leonard Field Test



Source: Trumer, Rockfall Impact Test

- ▶ Mitigate landslide hazards by capturing the materials and resisting the impact
- ▶ Dissipate the impact energy by large deformation of the system and / or mobilisation of energy-dissipating devices

Typical components



Principal net

Secondary mesh

Wire ropes

Post

Brake elements

Anchor foundation



Variations among products

Principal Net



Geobrugg



Trumer (2013)



Isofer (2012)

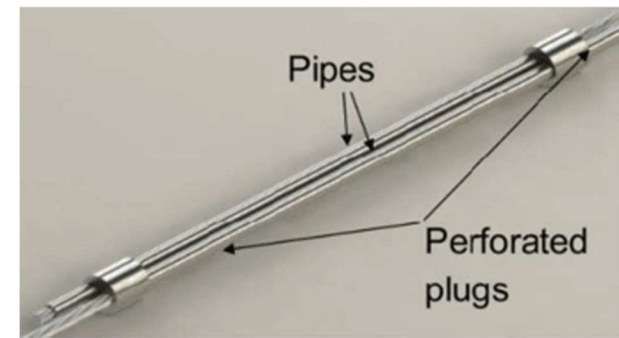


Others such as cable and brake element arrangement, post and anchor head connection details, etc.

Brake Elements



Geobrugg



Maccaferri



Trumer

Rockfall flexible barriers

- ▶ Energy rating certified by full-scale impact tests
- ▶ Designed by Empirical Approach or Analytical Approach

Maccaferri RMC 300A (3000kj)



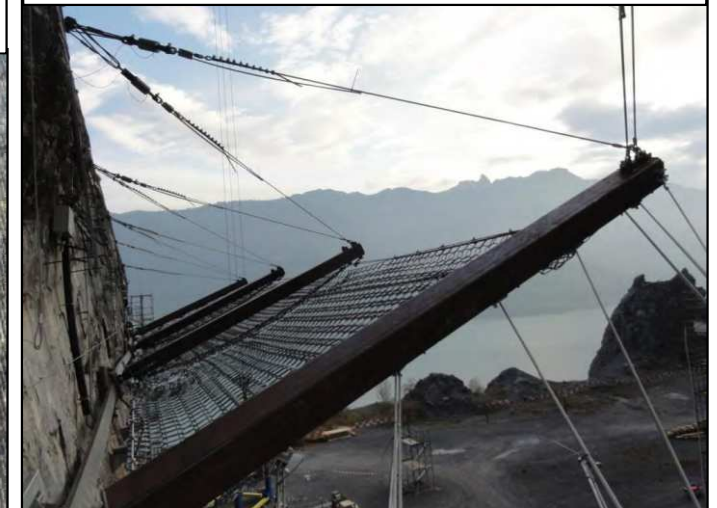
Trumer TSC-3000-ZD (3000kj)



Geobrugg RXE-5000 (5000kj)

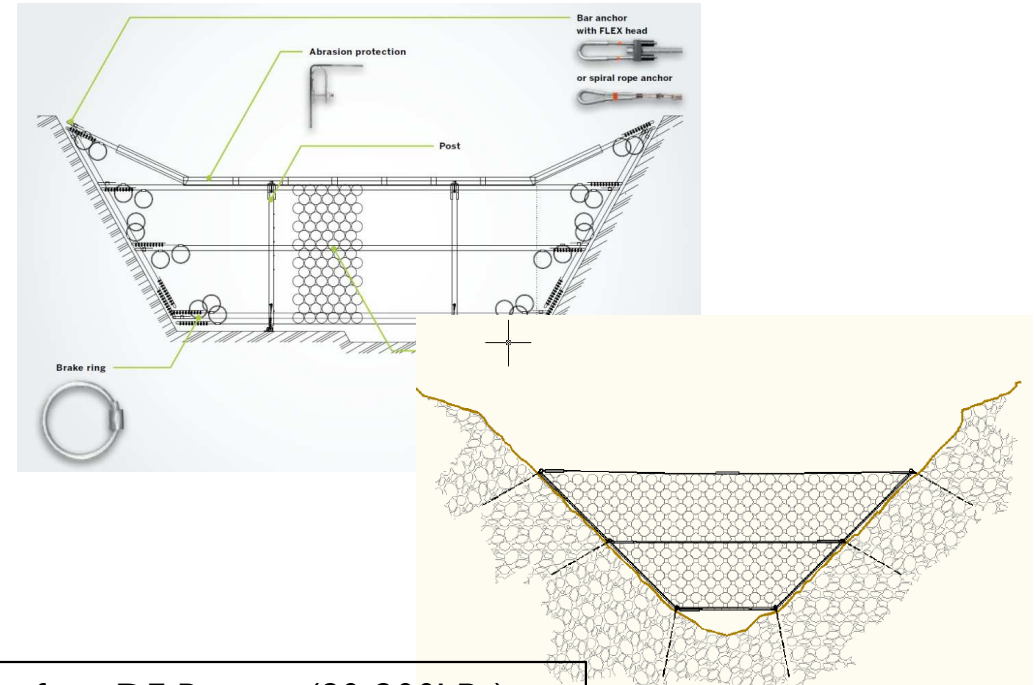


Geobrugg RXE-8000 (8000kj)



Debris-resisting flexible barriers

- ▶ Pressure rating certified by full-scale impact tests & numerical analyses
- ▶ Usually require site-specific design using Analytical Approach



Geobrugg VX Barrier (60-160kPa)

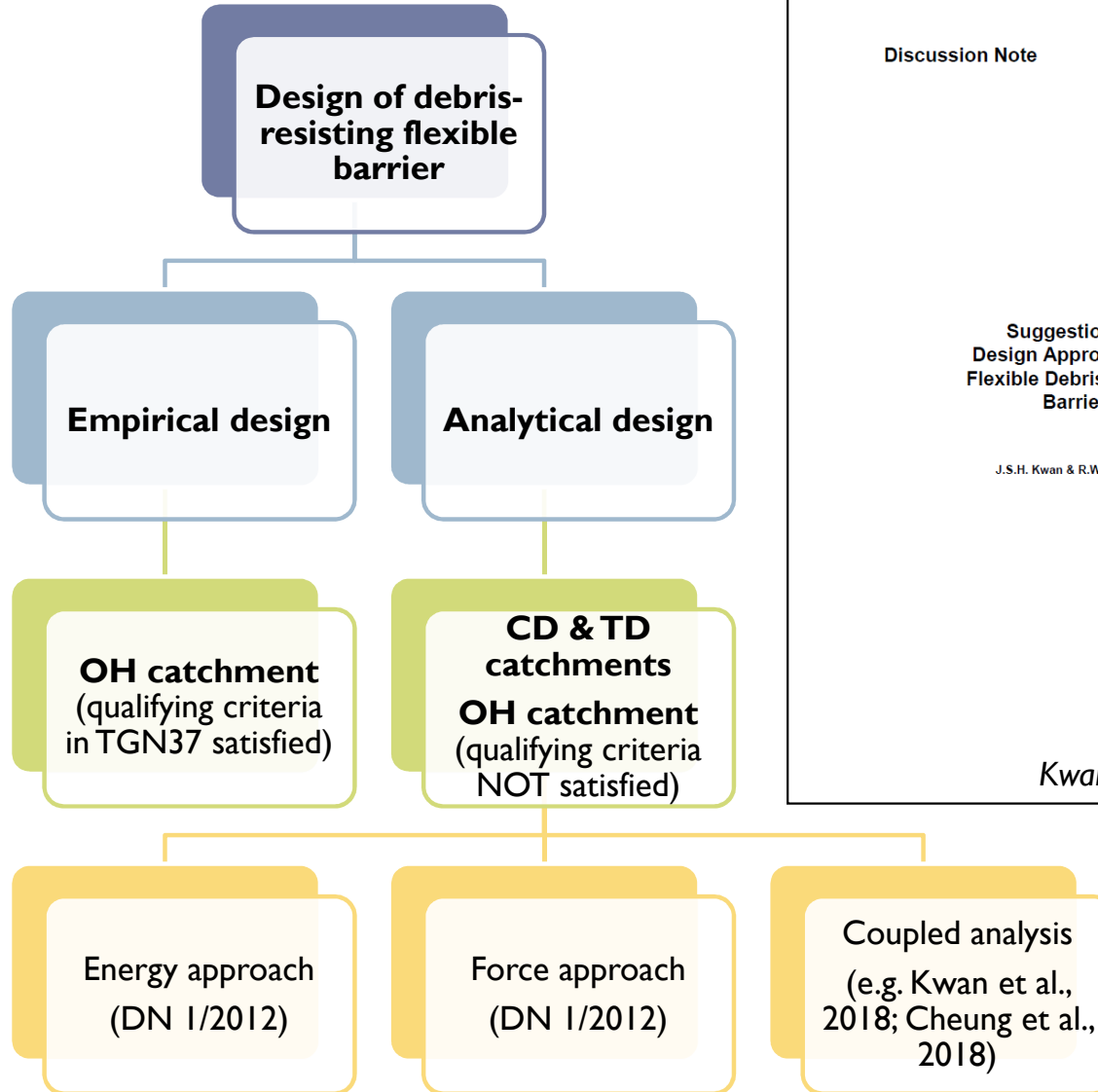


Maccaferri DF Barrier (80-200kPa)



Maccaferri (2011)

Local design practice



Discussion Note DN 1/2012

Suggestions on Design Approaches for Flexible Debris-resisting Barriers

J.S.H. Kwan & R.W.M. Cheung

April 2012
Standards and Testing Division
Kwan & Cheung (2012)

Geotechnical Engineering Office, Civil Engineering and Development Department
The Government of the Hong Kong Special Administrative Region

GEO Technical Guidance Note No. 37 (TGN 37)
Guidelines on Empirical Design of Flexible Barriers for Mitigating Natural Terrain Open Hillslope Landslide Hazards

Issue No. 1 | Revision: A | Date: 24.4.2014 | Page: 1 of 18

1. SCOPE

1.1 This Technical Guidance Note (TGN) presents guidelines on use of prescribed flexible barriers in mitigating natural terrain open hillslope landslide (OHL) hazards affecting existing developments under the Landslip Prevention and Mitigation Programme (LPMiP). The guidelines may also be adopted in dealing with OHL hazards under public works projects, private developments and redevelopments, and Housing Department projects.

1.2 Any feedback on this TGN should be directed to Chief Geotechnical Engineer/Landslip Preventive Measures 2 of the GEO.

2. TECHNICAL POLICY

2.1 The technical recommendations promulgated in this TGN were agreed by GEO Geotechnical Control Conference (GCC) on 17 June 2014.

3. RELATED DOCUMENTS

3.1 Chan, C.H.W., Ting, S.M. & Wong, A.C.W. (2012). *Development of Natural Terrain Landslip Alert Criteria (Special Project Report No. SPR 1/2012)*. Geotechnical Engineering Office, Hong Kong, 68p.

3.2 Cheng, P.F.K. & Ko, F.W.Y. (2010). *An Updated Assessment of Landslide Risk Posed by Man-made Slopes and Natural Hillsides in Hong Kong (GEO Report No. 252)*. Geotechnical Engineering Office, Hong Kong, 46p.

3.3 FSJV (2010). *Summary Report on the Identification of June 2008 Natural Terrain Landslides on Lantau Island (Preliminary)*. Fugro Scott Wilson Joint Venture. A Report for the Geotechnical Engineering Office, Hong Kong.

3.4 GEO (1984). *Geotechnical Manual for Slopes (Second Edition)*. Geotechnical Engineering Office, Hong Kong, 295p.

3.5 GEO (2012). *Guidelines on Assessment of Debris Mobility for Open Hillslope Failures (GEO Technical Guidance Note No. 34)*. Geotechnical Engineering Office, Hong Kong, 16p.

3.6 GEO (2014). *Guidelines on Enhanced Approach for Natural Terrain Hazard Studies (GEO Technical Guidance Note No.36)*. Geotechnical Engineering Office, Hong Kong, 18p.

3.7 Kwan, J.S.H., Koo, R.C.H. & Ko, F.W.Y. (2013). *A Pilot Study on the Design of Multiple Debris-resisting Barriers (Technical Note No. TN 3/2013)*. Geotechnical Engineering Office, Hong Kong, 69p.

TGN 37

Empirical design approach (TGN 37)

- ▶ Applicable against **OHL hazard**
- ▶ Can be adopted if
 - ▶ It is for **holistic** risk mitigation, or
 - ▶ The following **qualifying criteria** are satisfied:

Qualifying Criteria for Using the Empirical Design Approach

- 5.2 The empirical design approach should generally only be applied to OH catchments (or sub-catchments) that satisfy the following criteria:
- (a) Within a plan distance of 100 m from the affected facilities, no recent landslide with a volume greater than 100 m³, and no recent landslide with a volume between 50 m³ and 100 m³ with debris reaching closer than 20 m on plan from the affected facilities, has occurred on the OH catchment.
 - (b) Within a plan distance of 100 m from the affected facilities, no continuous steeply inclined ground surface of more than 40° in gradient and 40 m in length on plan along a runout path is present on the OH catchment.
 - (c) There is no evidence of existing significant signs of distress, continuing hazardous movement or incipient instability within the OH catchment, which could affect a facility covered by the facility types given in Table 1. Appropriate mitigation measures should be designed to address the hazards from such features.
 - (d) No newly emerged hazardous situation has evolved as a result of the occurrence of new landslide(s) (e.g. landslides which occurred during the course of NTHS), development of new signs of distress and hazardous movement, or exacerbation of existing signs of distress and hazardous movement on the OH catchment, particularly where there is concern of further hillside deterioration leading to instability.
 - (e) The OH catchment is not susceptible to deep-seated landslide hazards.

Table 1 – Empirical design of prescribed flexible barrier against OHL hazard

Facility	Proximity		
	Very Close (e.g. if angular elevation from the facility is $\geq 30^\circ$)	Moderately Close (e.g. if angular elevation from the facility is $<30^\circ$ and $\geq 25^\circ$)	Far (e.g. if angular elevation from the facility is $< 25^\circ$)
Buildings and sensitive structures ⁽²⁾	R1 + baffles	R1	R3
Groups 1&2 other than buildings and sensitive structures	R1	R2	Nil
Group 3	R2	R3	Nil

Notes:

- (1) The facility group and proximity class should be assessed following the guidelines given in GEO Report No. 138.
- (2) Sensitive structures refer to those facilities including Potential Hazardous Installations, tunnel portal, petrol station, railway platform and MTR exit that may involve severe consequence when affected by landslides, in accordance with the facility classification adopted in GEO Report No. 191.
- (3) If boulder/rock fall hazards also exist, the kinetic energy of the boulder/rock hitting the barrier should not exceed the energy rating of the barrier, and the corresponding bounce height of the boulder/rock should not exceed the height of the barrier.
- (4) R1: 3,000 kJ flexible rock fall barrier with minimum height of 4 m.
R2: 2,000 kJ flexible rock fall barrier with minimum height of 3 m.
R3: 1,000 kJ flexible rock fall barrier with minimum height of 3 m.
- (5) 'Baffles' comprise structural steel sections or steel hollow sections filled with concrete placed in rows uphill of the flexible barrier. They are prescribed measures for enhancing the robustness of the mitigation scheme, by reducing the impact force/energy of the landslide debris reaching the barriers and facilitating debris deposition.
- (6) A suitable clearance between the barrier and the affected facility should be provided to allow for deformation of the barrier upon hitting by landslide debris/boulder/rock.
- (7) The stability of the hillside/slopes below the barrier including the effects of the foundations of the barrier on their stability should be assessed.

Analytical design approach

- ▶ Can be adopted if it is for mitigating
 - ▶ OHL hazards where the **qualifying criteria cannot be met**
 - ▶ **Debris flow hazards**

- ▶ **Three approaches**
 - ▶ **Energy** approach (Kwan & Cheung, 2012; Sun & Law, 2015)
 - ▶ **Force** approach (Kwan & Cheung, 2012; Sze et al., 2018)
 - ▶ **Coupled** analysis (e.g. Kwan et al., 2018; Cheung et al., 2018)

Energy Approach

- ▶ Key design consideration:

**Energy Dissipation Capacity (EDC) of barrier
> Energy loading (E) of debris flow**

- ▶ **Calculation of “E”**

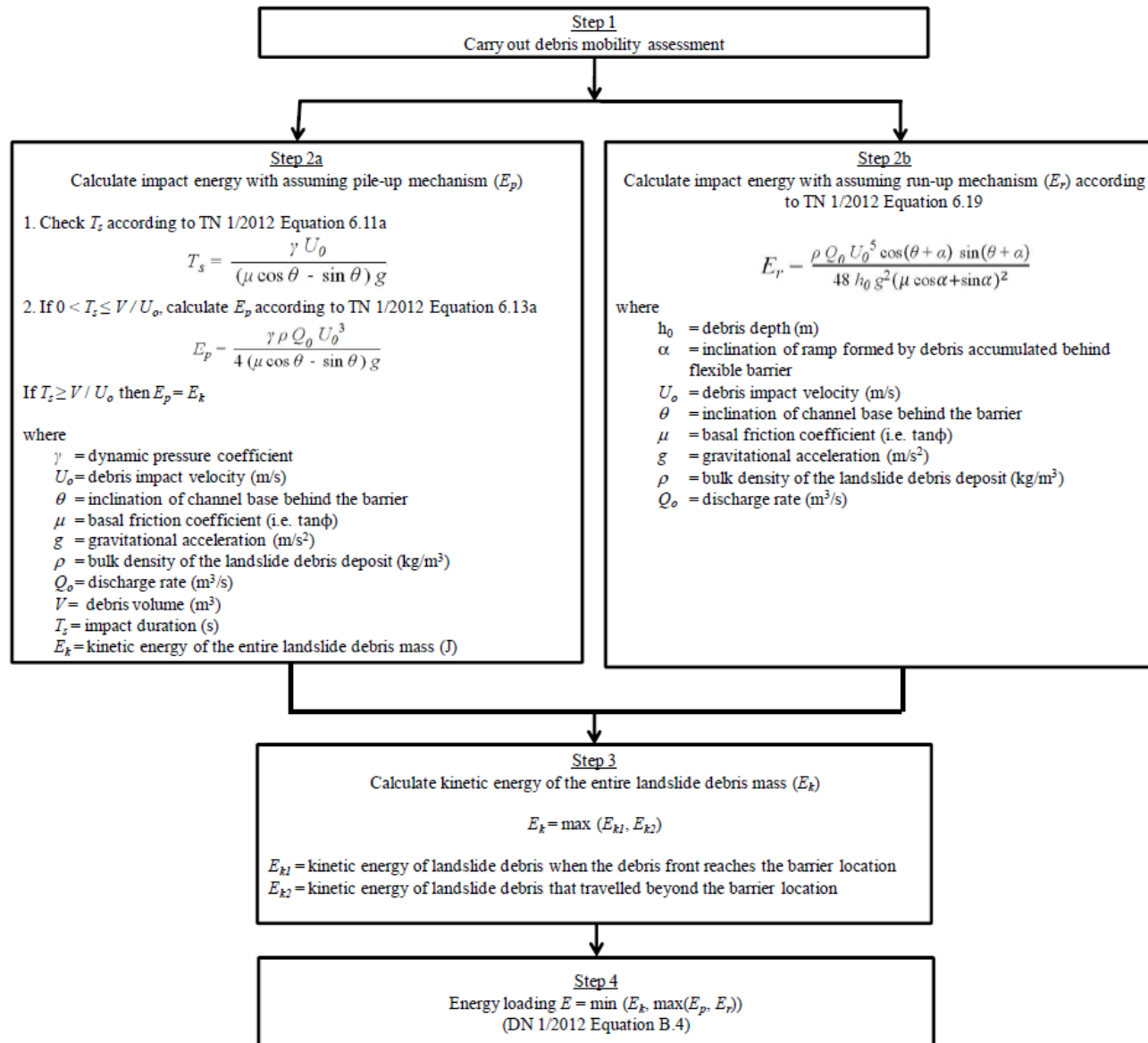
- ▶ What is the energy brought by debris flow to a flexible barrier?

**There is internal energy dissipation as the debris flows & interacts with the barrier*

$$E < \frac{1}{2} m_{\text{total}} v_{\text{max}}^2$$



Determine Energy Loading “E”



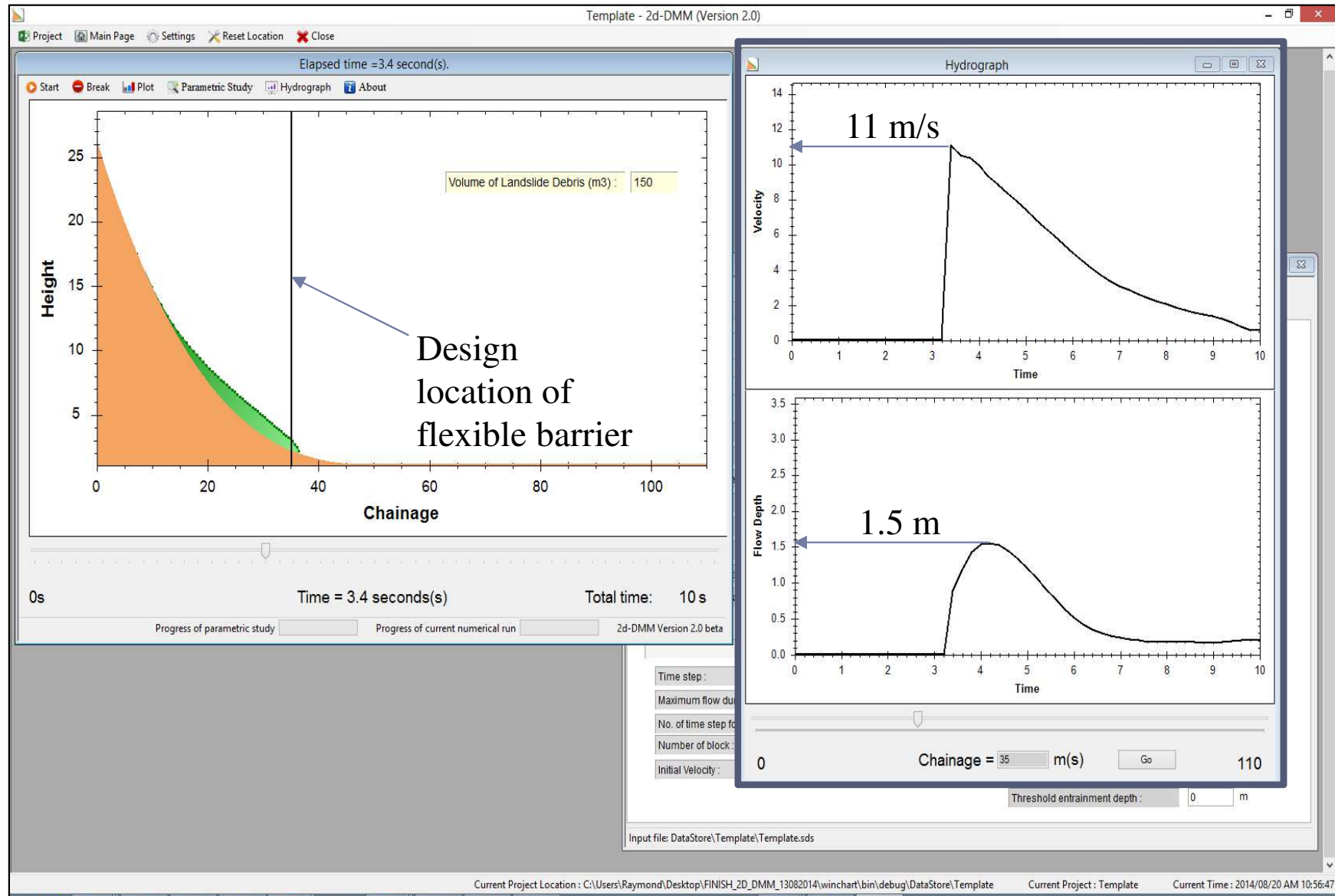
➔ Calculate the flow velocity and depth hydrograph at the design location of flexible barrier (TGNs 29, 34, 38)

➔ Calculate the upper bound impact energy based on pile-up and run-up mechanisms (GEO Report 309)

➔ Calculate the upper bound energy requirements by assuming no energy loss

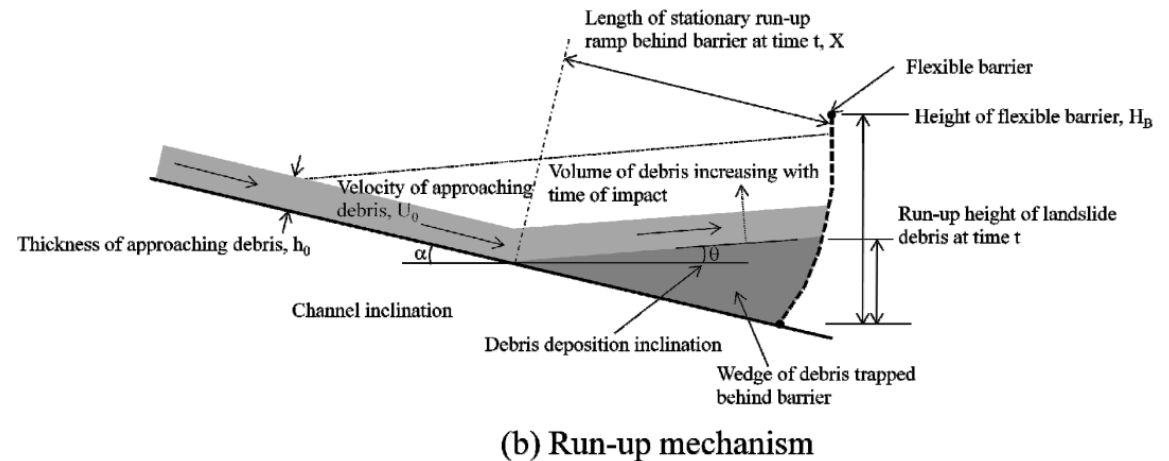
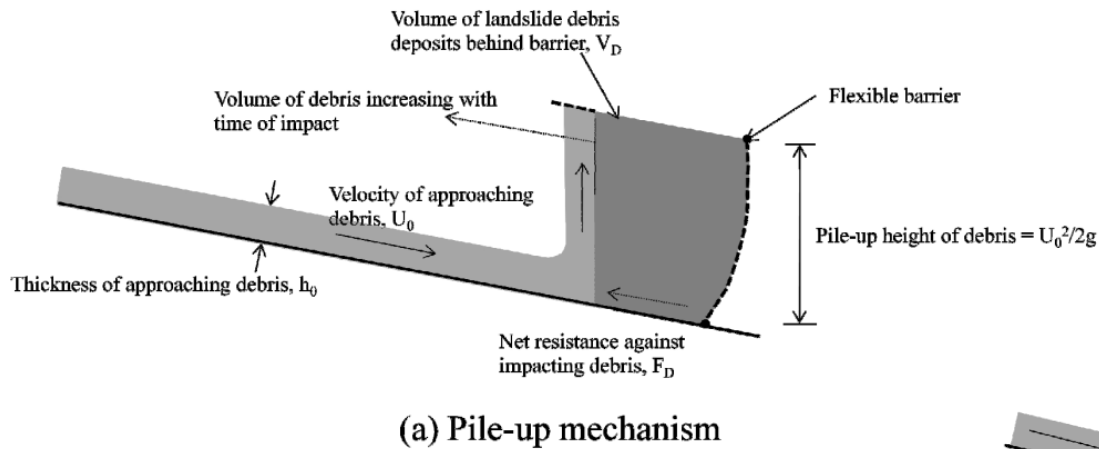
➔ Determine the design energy requirement of the flexible barrier i.e. “E”

Step 1 – Debris Mobility Assessment



Step 2 – Pile-up and run-up mechanisms (GEO Report 309)

- ▶ The energy required to be absorbed by the flexible barrier is calculated based on the limiting deposition processes of landslide debris



Note: there are some conditions under which the two mechanisms cannot be adopted
e.g. when slope angle \geq interface friction angle at base of debris plug, E_p is not applicable

Step 3 – Upper bound energy requirement

- ▶ Instead of taking the upper bound as E_{k1} and E_{k2} are defined:

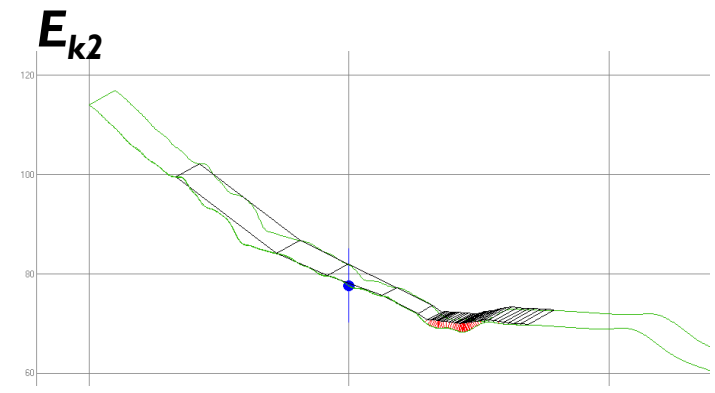
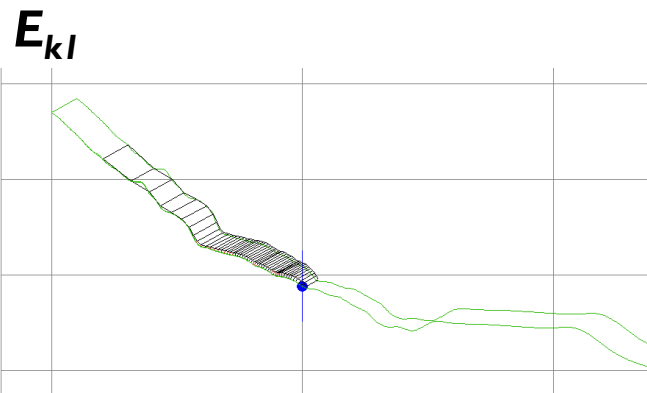
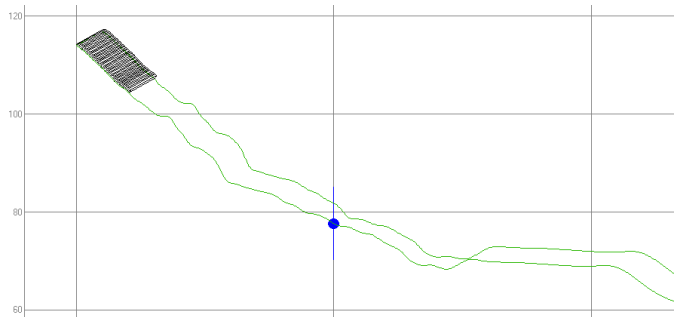
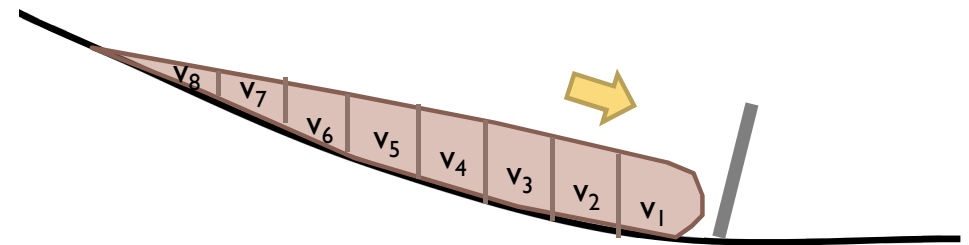
$$E = \frac{1}{2} m_{\text{total}} v_{\text{max}}^2$$

↓

Step 3
Calculate kinetic energy of the entire landslide debris mass (E_k)

$$E_k = \max(E_{k1}, E_{k2})$$


E_{k1} = kinetic energy of landslide debris when the debris front reaches the barrier location
 E_{k2} = kinetic energy of landslide debris that travelled beyond the barrier location



Determine Energy Dissipation Capacity “EDC”

- ▶ Key design consideration:

**Energy Dissipation Capacity (EDC) of barrier
> Energy loading (E) of debris flow**

- ▶ **EDC** can be established based on
 - ▶ structural analysis (Kwan & Cheung, 2012) 
 - ▶ field testing (TGN 37)

When the energy approach is adopted in analytical design of a flexible barrier, the energy capacity of a barrier established by full-scale rockfall (or other single-mass) tests should be scaled down to cater for the possibility of reduced energy capacity in the case of resisting landslide debris. Until better information becomes available, a scaling factor of not exceeding 75% should be adopted for designing a flexible barrier to mitigate landslide hazards from all types of catchments (i.e. CD, TD and OH).

- ▶ e.g. EDC of a certified proprietary rockfall barrier rated at 2000 kJ
= $2000 * 0.75 = 1500$ kJ.

Force Approach

Barrier Configuration

- Structural form vs site setting
- Structural capacity & retention capacity

Design Loading Scenarios

- Sequential applications of dynamic & static loadings

Debris-resisting Capacity

- Modelling to account for non-linear load-deformation behavior of barrier

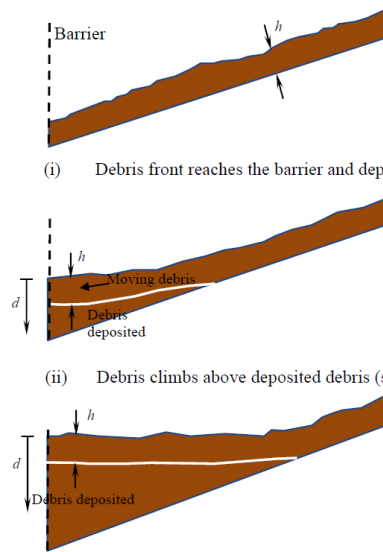
Overall Stability

- Ensure slope stability up to required safety standard

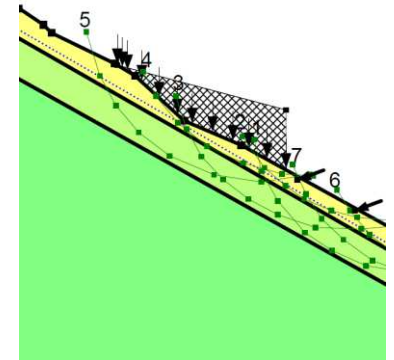
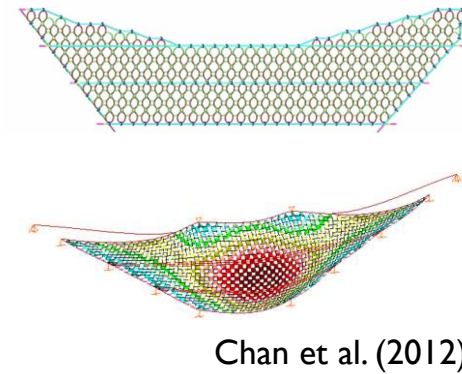
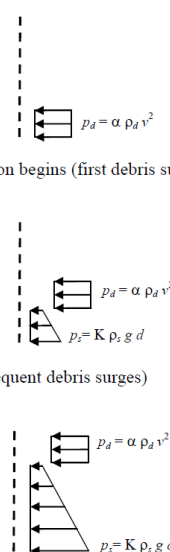


WSL (2009)

Flowing and Deposition Sequence of Debris



Loading on Barrier



Loadings

▶ Dynamic impact pressure

$$P_d = \alpha \rho_d v^2 \text{ — velocity}$$

2.0 2,200 kg/m³

▶ Static earth pressure

$$P_s = K d \rho_s g$$

1.0 deposited 2,200 kg/m³
depth

▶ Overflow drag

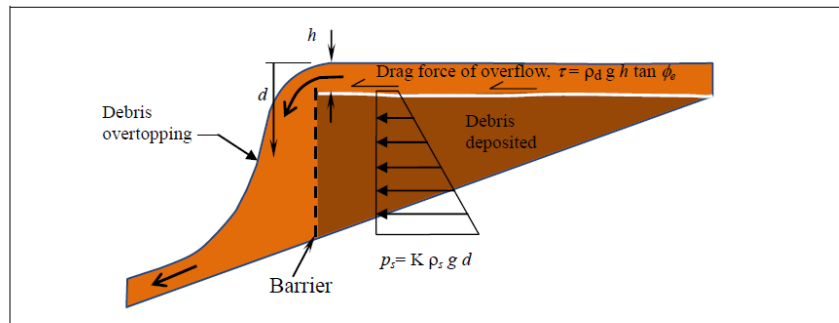


Figure B2 Loading on a Barrier due to Debris Overtopping

The shear stress which will give rise to the drag force should be determined by the equation:

$$\tau = h \rho_d g \tan \phi_e \dots\dots\dots (B.3)$$

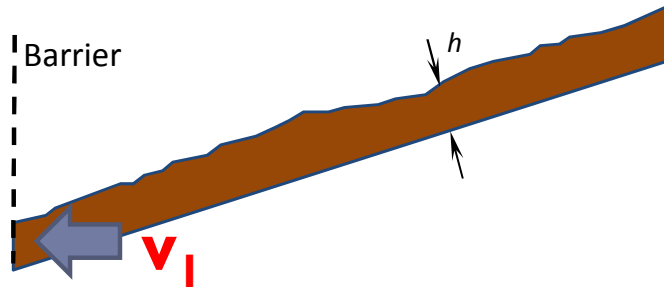
where h = thickness of debris surge
 $\tan \phi_e$ = equivalent coefficient of friction at the interface of the overtopping debris surge and the deposited debris and should be taken as $\tan \phi + v^2 / (h \xi)$ where v is velocity of overflow, ϕ and ξ are the apparent friction angle and turbulence coefficient adopted in the debris mobility analysis respectively (the second term, $v^2 / (h \xi)$, can be dropped when frictional rheological model is used)

▶ Boulders

(e) Where boulders with diameter greater than 2 m (or with volume exceeding a 2 m diameter sphere) in the debris flow are anticipated, suitable independent measures (e.g. baffles, debris-straining structures or in-situ boulder stabilisation) should be provided to reduce the impact of boulders on the flexible barrier.

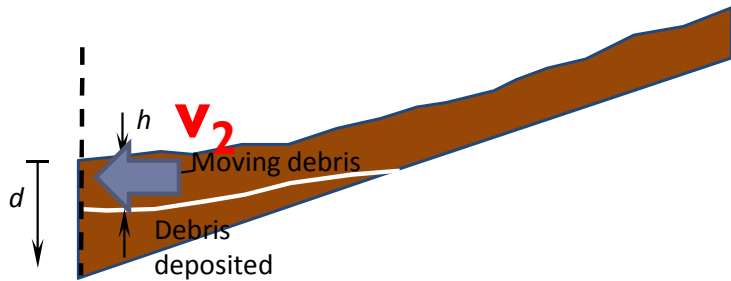
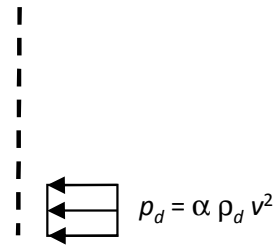
Debris impact scenario

Flowing and Deposition Sequence of Debris

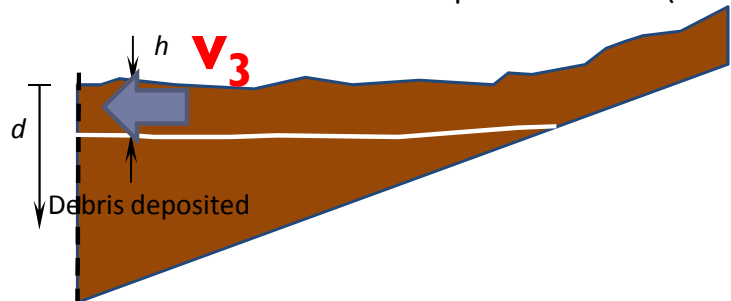
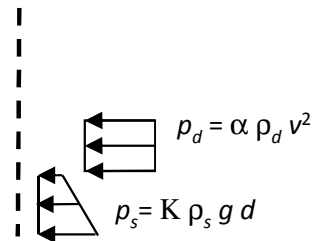


① Debris front reaches the barrier and deposition begins (first debris surge)

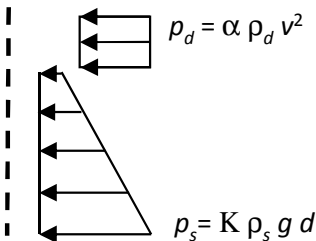
Loading on Barrier



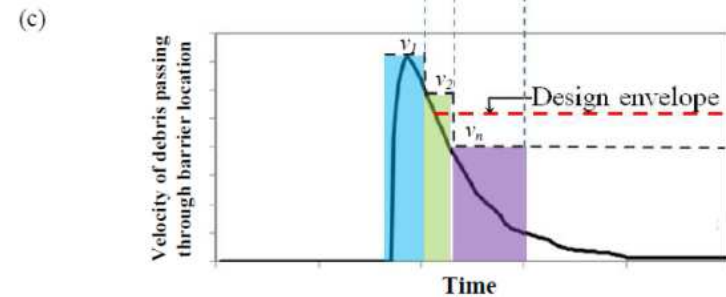
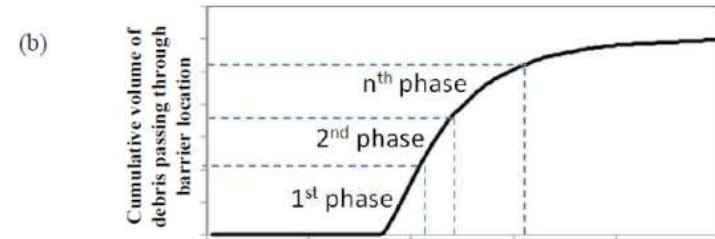
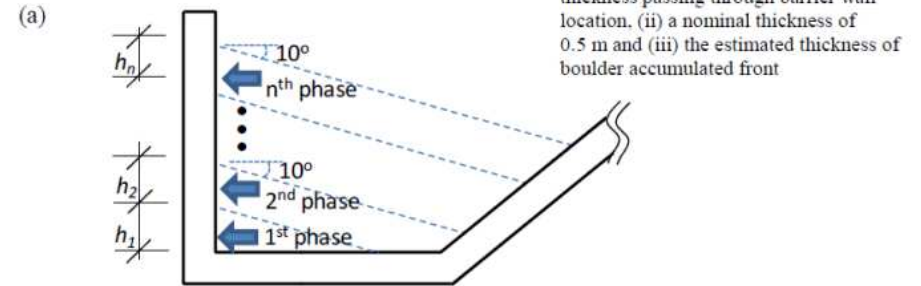
② Debris climbs above deposited debris (subsequent debris surges)



③ Debris piles up behind the barrier (last debris surge filling up the barrier)



$$v_1 > v_2 > v_3$$



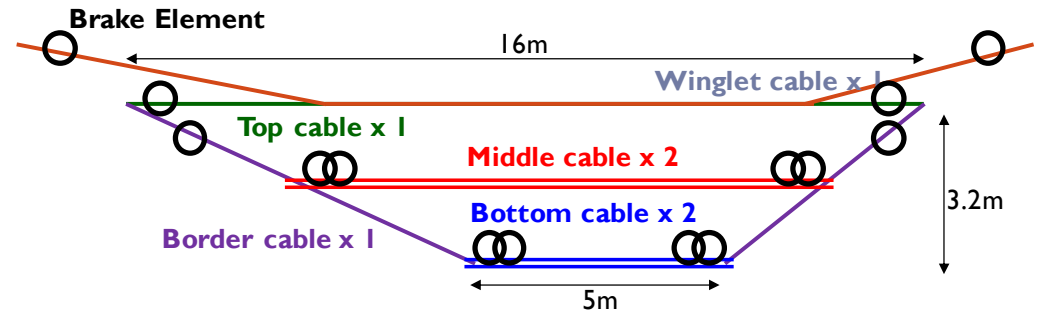
v_n = design impact velocity of the n^{th} phase ≤ 0.7 maximum debris velocity of the hydrograph

Barrier Configuring & Analysis

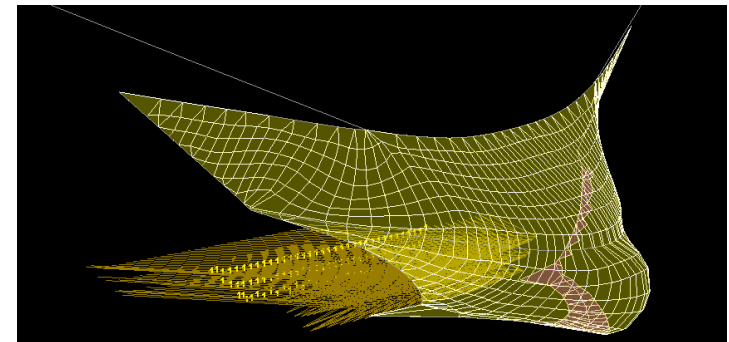
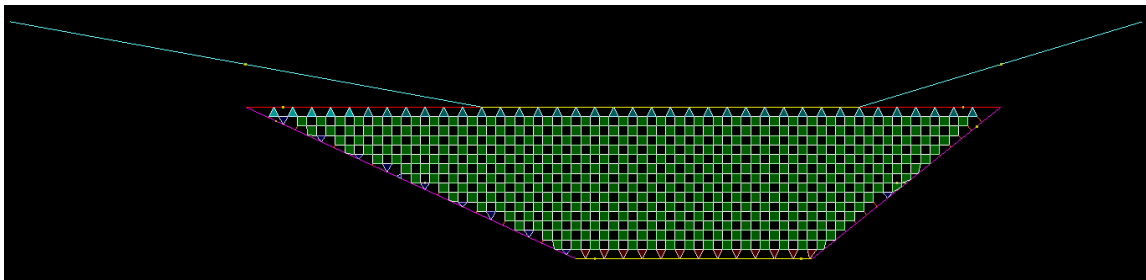
Site Setting



Barrier Configuration

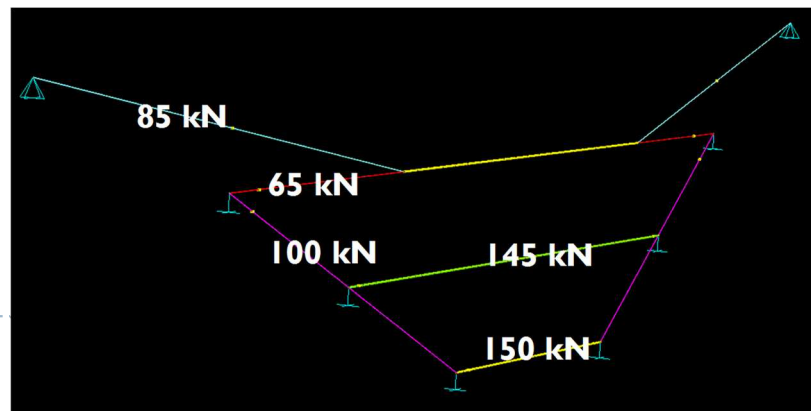


Structural Analysis



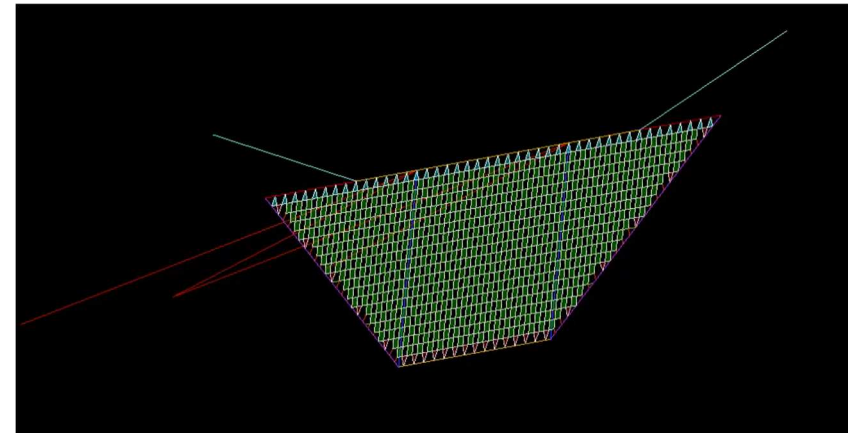
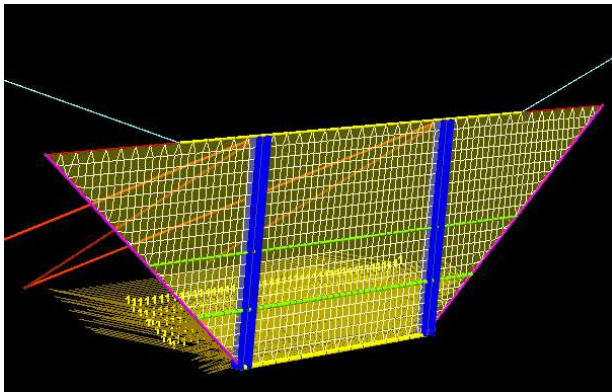
Design & Detailing

e.g. obtain maximum cable force

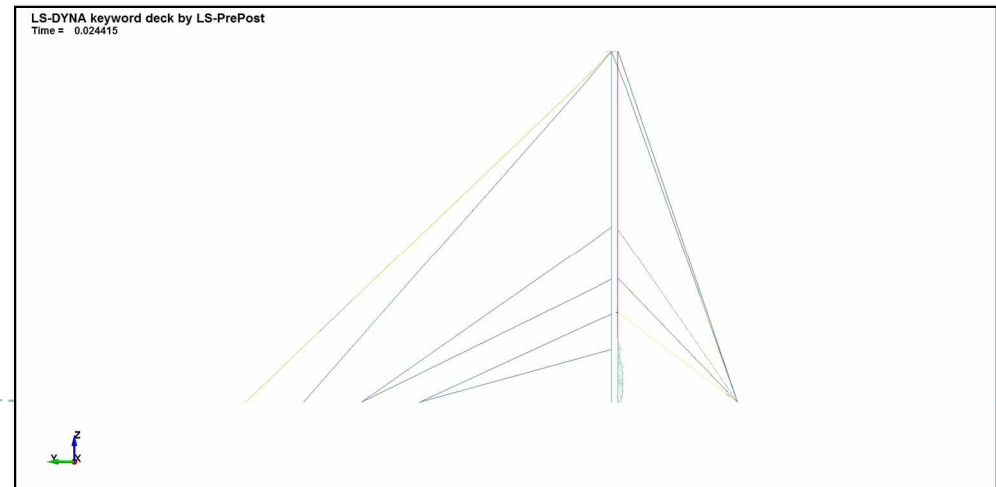
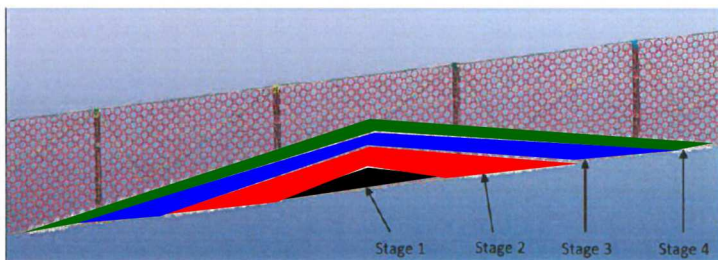
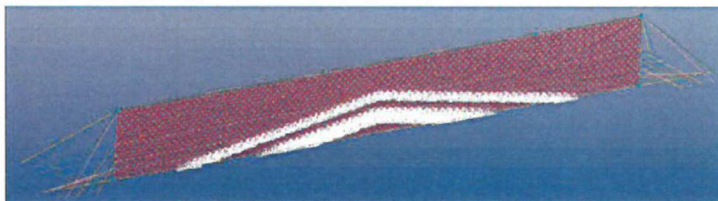


Numerical Programs

- ▶ Models that take into account the non-linear material behavior of flexible barriers under sequential loadings
- ▶ e.g. NIDA-MNN (Chan et al. 2012)



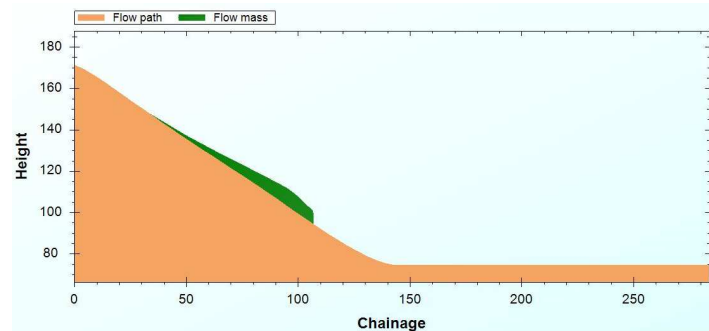
- ▶ e.g. LS-DYNA (Ng et al., 2012)



Coupled Analysis

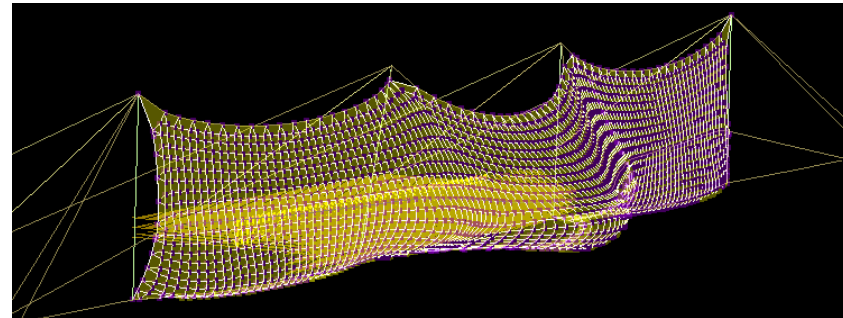
- ▶ Force approach is essentially a decoupled analysis

Debris mobility modelling



+

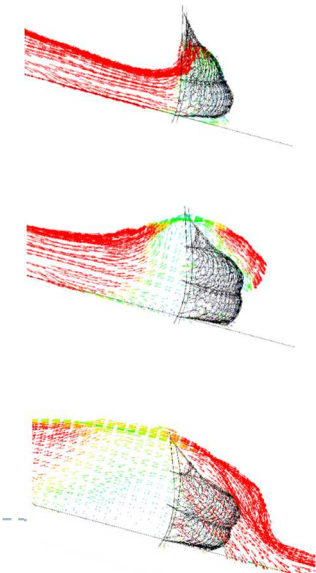
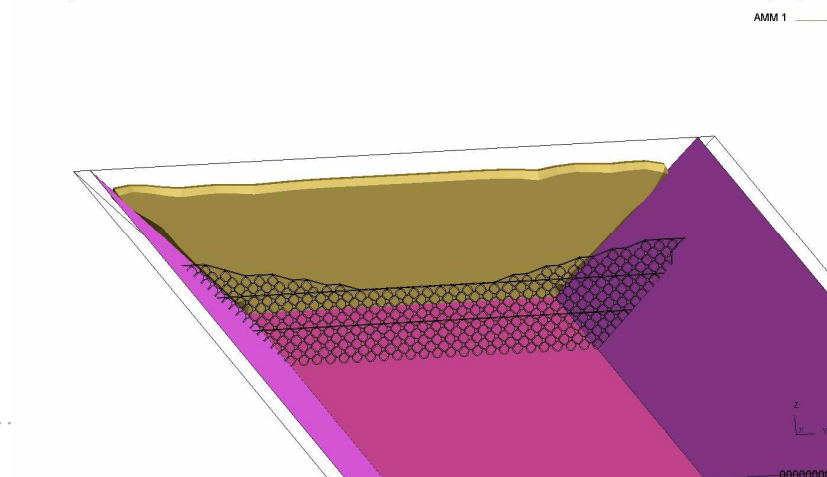
Structural response of barrier



- ▶ Coupled analysis explicitly consider the debris-barrier interaction



D3PLOT: Ilgraben



References

- ▶ Chan, S.L., Zhou, Z.H., and Liu, Y.P. (2012). Numerical Analysis and Design of Flexible Barriers Allowing for Sliding Nodes and Large Deflection Effects. Proceedings, Seminar on Natural Terrain Hazard Mitigation Measures, Hong Kong.
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- ▶ GEO (2014). GEO Technical Guidance Notes No. 37 (Rev. A) – Guidelines on Empirical Design of Flexible Barriers for Mitigating Natural Terrain Open Hillslope Landslide Hazards. Geotechnical Engineering Office, Hong Kong, 18 p.
- ▶ GEO (2015). GEO Technical Guidance Notes No. 44 – Assessment of Landslide Debris Impact Velocity for Design of Debris-resisting Barriers. Geotechnical Engineering Office, Hong Kong, 4 p.
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- ▶ Geobruigg (2012). Evaluation Report for the assessment of ETA-12/0213. Geobruigg AG, 52 p.
- ▶ Kwan, J.S.H. and Cheung, R.W.M. (2012). Suggestions on Design Approaches for Flexible Debris-resisting Barriers – Discussion Note DN I/2012. Geotechnical Engineering Office, Hong Kong, 91 p.
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- ▶ Kwan, J.S.H., Sze, E.H.Y. and Lam, C. (2018). Finite element analysis for rockfall and debris flow mitigation works – Canadian Geotechnical Journal, <https://doi.org/10.1139/cgj-2017-0628>.
- ▶ Maccaferri (2011). Mac.ro. System – Debris flow barrier – Technical data sheet (Rev. 08). Officine Maccaferri S.p.A., Italy, 2 p.
- ▶ Ng, A.K.L., Williamson, S.J. & Chong, A.K.T. (2012). Developments in design considerations and use of flexible barriers as mitigation measures for channelised debris flow and open hillslope failures - A case study, Proceedings of the One Day Seminar on Natural Terrain Hazard Mitigation Measures, Hong Kong, p.61-66.
- ▶ Sun, H.W. & Law, R.P.H. (2015). A Preliminary Study on Impact of Landslide Debris on Flexible Barriers. GEO Report No. 309, 47 p.
- ▶ Sze, E.H.Y., Koo, R.C.H., Leung, J.M.Y. & Ho, K.K.S. (2018). Design of flexible barriers against sizeable landslides in Hong Kong, HKIE Transactions, Vol. 25(2), p.115-128.
- ▶ Trumer (2013). Product Catalogue – Rockfall Protection, Avalanche Protection, Rock and Slope Stabilisation. Trumer Schutzbauten, 224 p.
- ▶ WSL (2009). Full-scale Testing and Dimensioning of Flexible Debris Flow Barriers. Swiss Federal Institute for Forest, Snow and Landscape Research, Research Unit Avalanches, Debris and Rockfall, 22 p.



Thank You

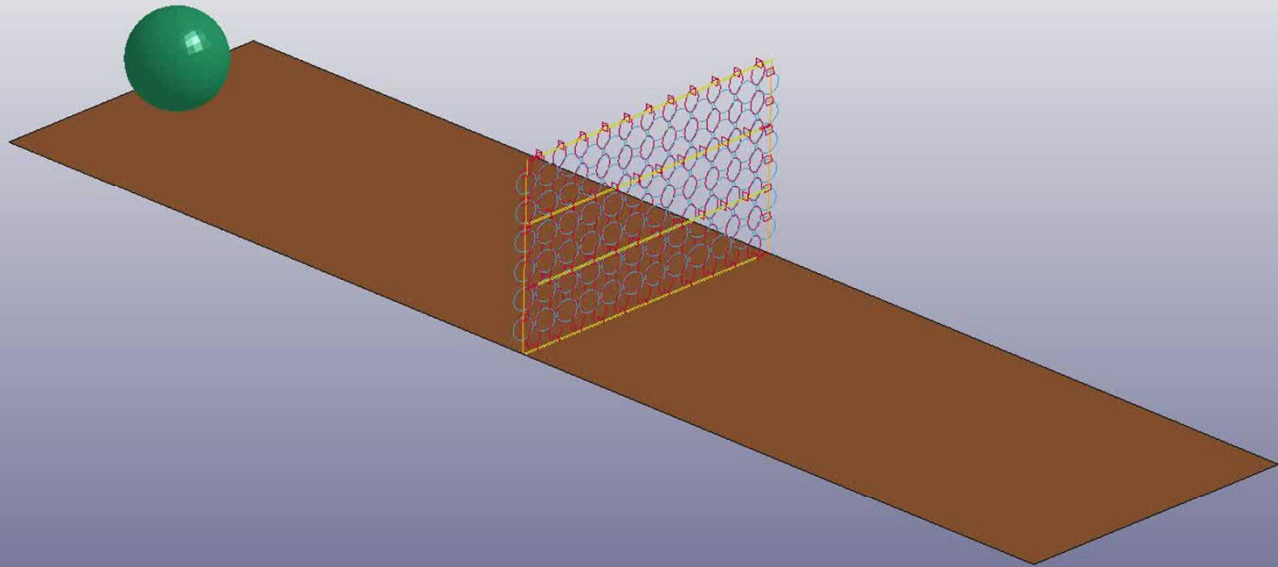
Introduction of LS-DYNA

Workshop on Numerical Modelling for Design of Flexible Debris-resisting Barriers

16 Apr 2019

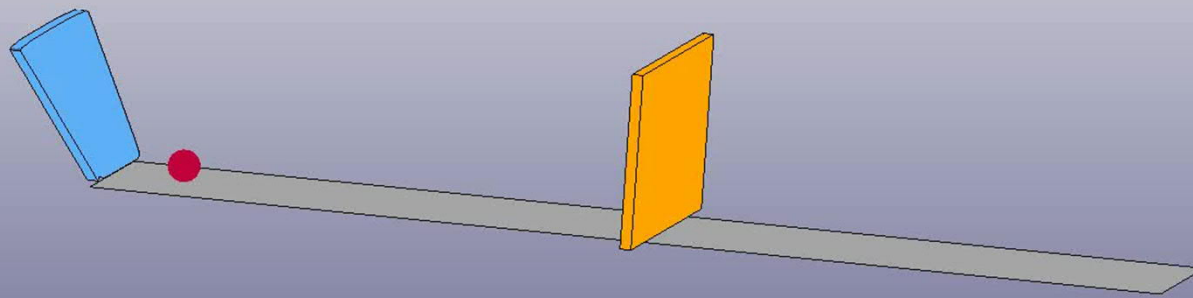
Flexible barrier study_Case_3

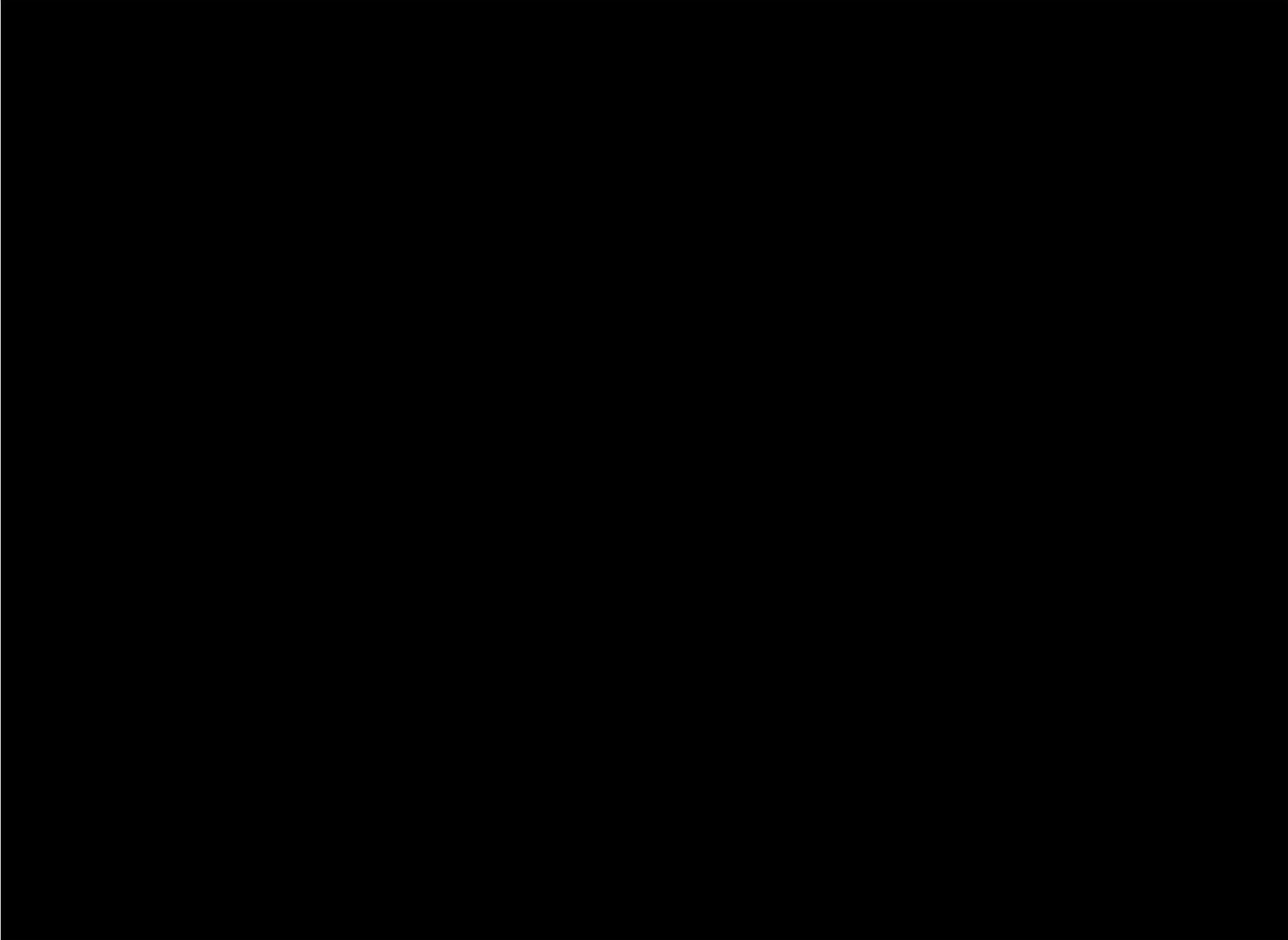
Time = 0



Video - debris flow impacting a rigid barrier

RMC160DF_6m/s_150m3
Time = 0





Outline

- Background of LS-DYNA
- Basics of a LS-DYNA model
- General modelling guidelines
 - Element type and formulation
 - Typical material models in modelling flexible barriers & debris
 - Contact modelling
 - Initial and boundary conditions
 - Control parameters Unit system
- Post-Processing guidelines
- Useful references

Background of LS-DYNA

- Developed by **L**ivermore **S**oftware Technology Corporation, California, USA
- 2D / 3D, particularly suitable for nonlinear, transient **dynamic** finite element analysis

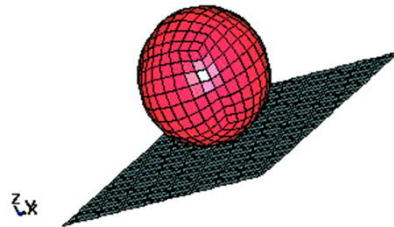
TENSION TEST SIMULATION, MAT=24, DISPLA
Time = 0



y
z x

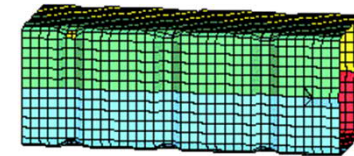
Tension test

SPHERE1.K
Time = 0



Boulder hits a elastic plate

SHORT CRUSH TUBE IMPACTED BY A MOVING W
Time = 0

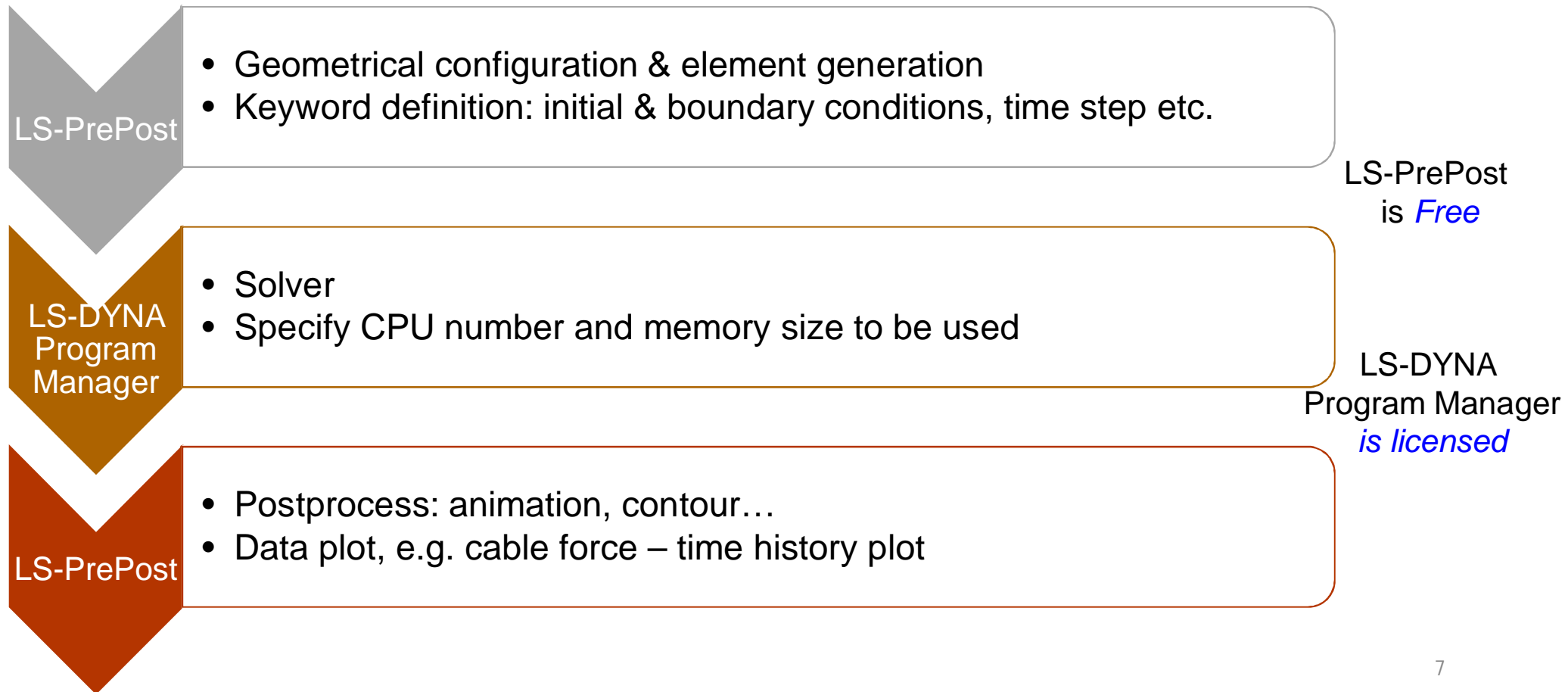


y
z x

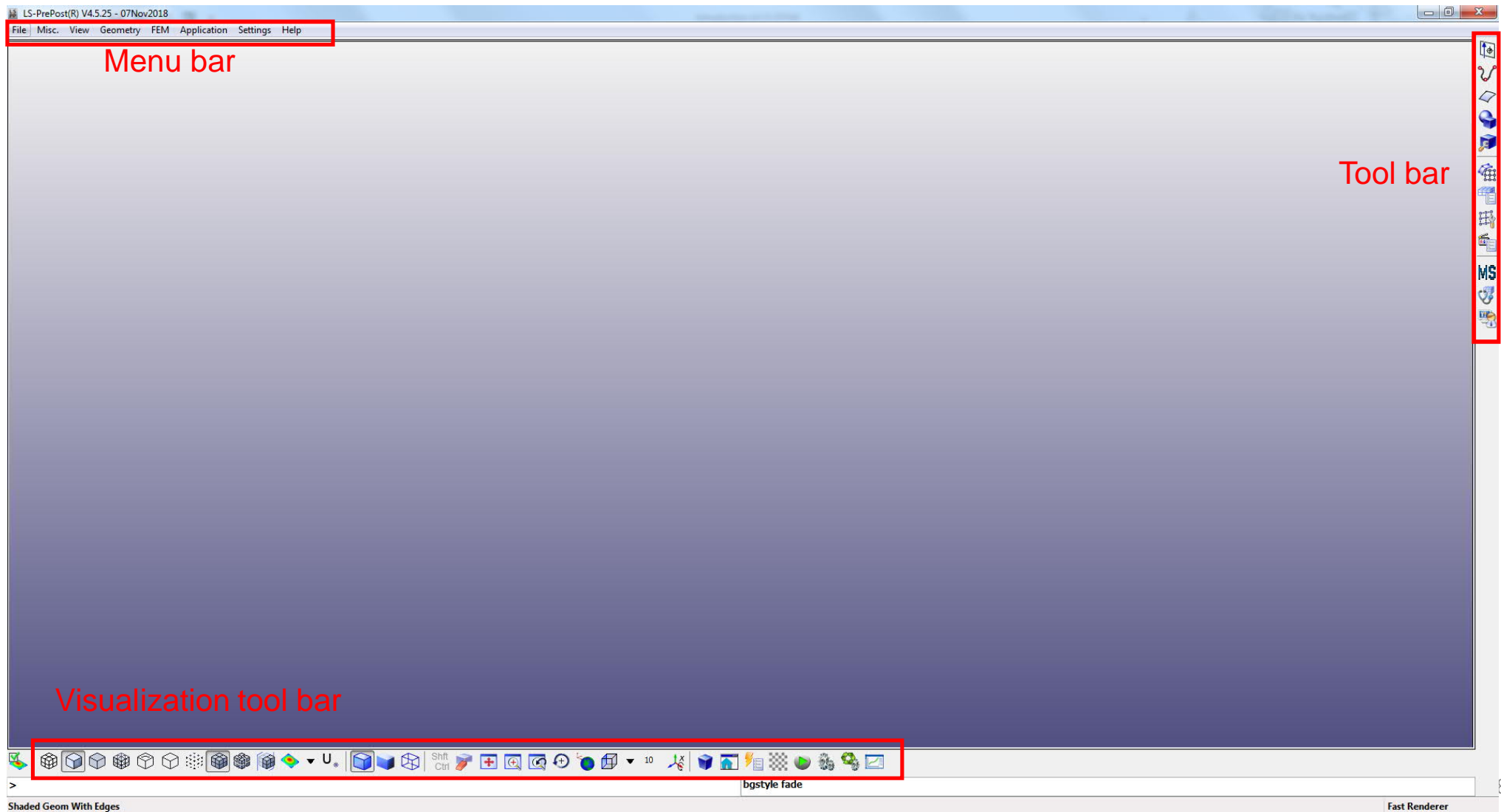
Compression of crush tube

Basics of a LS-DYNA model

- A LS-DYNA model: keyword file format – *xxxxx.k*



LS-PrePost



Generate keyword file using LS-PrePost

LS-PrePost(R) V4.5.25 - 07Nov2018-64bit S_DYNA_Project\99_16Apr2019_Presentation\sphere1.k\sphere1.k

Model tree: Assembly 1, FEM Parts, H 1, S 2, Keyword Entity, Boundary, Spc, Contact, General, Initial, Velocity

Geometrical view: A 3D visualization of a sphere on a blue grid plane.

Keyword panel: Keyword Manager window showing a list of keywords and their counts.

Input card, e.g. material data input: Keyword Input Form window showing a table of material properties.

Tool to prop out keyword panel: A red arrow points to a button in the top right toolbar.

Keyword Manager

Name	Count
BOUNDARY	124
SPC_NODE	124
CONTACT	1
CONTROL	8
DATABASE	3
ELEMENT	2948
INITIAL	1
KEYWORD	1
MAT	2
020-RIGID	1
024-PIECEWISE_LINEAR_PLASTICITY	1
NODE	3234
PART	2
SECTION	2
TITLE	1

Keyword Input Form

*MAT_PIECEWISE_LINEAR_PLASTICITY_(TITLE) (024) (1)

MID	RO	E	PR	SIGY	ETAN	FAIL	TDEL
1	7.830e-06	200.00000	0.3000000	2000.0000	1.0000000	0.3000000	0.0

Material arrange

GroupBy: Model, Sort: Type, List: All

Buttons: Model Check, Keyword Del, ResForm, ExpandAll, CollapseAll, Done

quat 0.037331 0.337463 0.803160 0.133006,
pan 216.987610 -107.328125;

9

Components of a typical keyword file

```

*KEYWORD
*TITLE
sphere1.k
*NODE
$
*ELEMENT_SOLID
$
*SECTION_SOLID
1
*SECTION_SHELL
2
2.500000 2.500000 2.500000 2.500000 0.000000
*MAT_PIECEWISE_LINEAR_PLASTICITY
$ mid ro e pr sigy etan failps
$ e/p and
$
*MAT_RIGID
1 7.83000-6 200.00000 0.3000000 0.0000000 0.0000000 0.0000000
*PART
1 1 1 0 0 0 0
*PART
2 2 2 0 0 0 0
*initial_velocity_generation
1,2,...,-89
*BOUNDARY_SPC_NODE
$
    
```

Geometrical information: coordination of each node

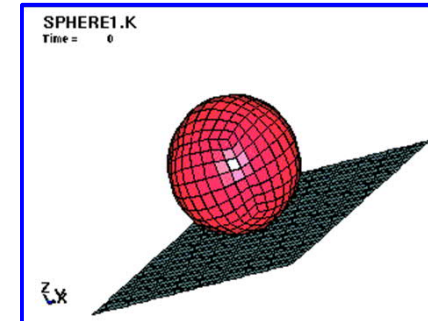
Element information: which nodes form a specific type of element

Section information: such as shell, solid, beam etc.

Material constitutive model, e.g. soil, steel

Which section, material etc. form which part

Define initial & boundary conditions



```

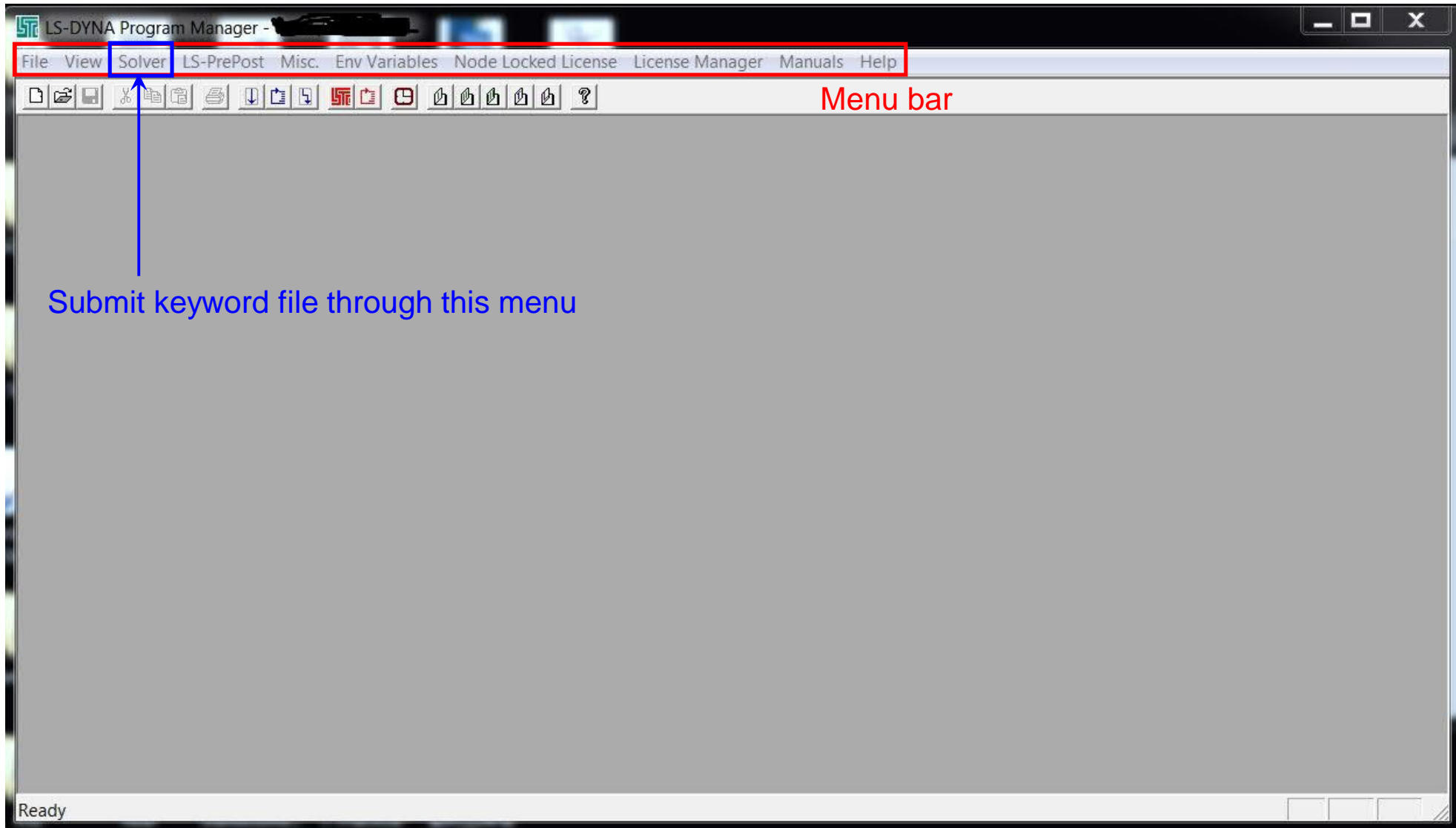
*contact_surface_to_surface
1,2,3,3
*CONTROL_TERMINATION
1.000000 0 0.000000 0 0.000000
*CONTROL_TIMESTEP
0.000000 0.000000 0 0.000000 0.000000 0 0
*CONTROL_SHELL
0.000000 0 0 0 0 0 0
*CONTROL_DAMPING
0 0.000000 0.000000 0.000000 0.000000 0 0.000000
*CONTROL_CONTACT
0.000000 0.000000 0 0 0 0 0
0 0 0 0 0.000000 0 0
*CONTROL_OUTPUT
0 0 0 0 0.000000 0 0
*CONTROL_ENERGY
1 2 1 1
*DATABASE_BINARY_D3PLOT
0.100000 0
*DATABASE_BINARY_D3THDT
10.000000
*DATABASE_EXTENT_BINARY
0 0 0 0 0 0 0
0 0 0 0 0 0 0
*END
    
```

Define how two parts interact

Define when model stops running, time step etc.

Define which information to be output in the result file

LS-DYNA Program Manager



Computation status

```
total energy / initial energy.. 6.39712E-01
energy ratio w/o eroded energy. 6.39712E-01
global x velocity..... 0.00000E+00
global y velocity..... 3.09588E-01
global z velocity..... -8.41055E-02
```

```
number of shell elements that
reached the minimum time step.. 0
1 t 0.0000E+00 dt 4.61E-06 flush i/o buffers
1 t 0.0000E+00 dt 4.61E-06 write d3plot file
```

```
Summary of edge-to-edge contact interface # = 1
number of warnings for interpenetration = 1998
number of warnings for segment deletion = 0
cpu time per zone cycle..... 0 nanoseconds
average cpu time per zone cycle.... 2852 nanoseconds
average clock time per zone cycle.. 2852 nanoseconds
```

```
estimated total cpu time = 295733 sec ( 82 hrs
estimated cpu time to complete = 295727 sec ( 82 hrs
estimated total clock time = 295733 sec ( 82 hrs
estimated clock time to complete = 295727 sec ( 82 hrs
```

$$B_n = B_{n-1} + (A_n - A_{n-1}) * C_n, n - \text{row number}$$

A B C Termination time
(cycle) (current time) (Time step) = 5.000E+00

5000	t 2.3049E-02	dt 4.61E-06	flush i/o buffers
10000	t 4.6093E-02	dt 4.61E-06	flush i/o buffers
15000	t 6.9127E-02	dt 4.61E-06	flush i/o buffers
20000	t 9.2149E-02	dt 4.60E-06	flush i/o buffers
21705	t 9.9997E-02	dt 4.60E-06	write d3plot file
25000	t 1.1516E-01	dt 4.60E-06	flush i/o buffers
30000	t 1.3816E-01	dt 4.60E-06	flush i/o buffers
35000	t 1.6115E-01	dt 4.60E-06	flush i/o buffers
40000	t 1.8413E-01	dt 4.59E-06	flush i/o buffers
43454	t 2.0000E-01	dt 4.59E-06	write d3plot file
45000	t 2.0710E-01	dt 4.59E-06	flush i/o buffers
50000	t 2.3004E-01	dt 4.58E-06	flush i/o buffers
55000	t 2.5285E-01	dt 4.54E-06	flush i/o buffers
60000	t 2.7538E-01	dt 4.46E-06	flush i/o buffers
65000	t 2.9752E-01	dt 4.39E-06	flush i/o buffers
65564	t 3.0000E-01	dt 4.38E-06	write d3plot file
70000	t 3.1933E-01	dt 4.33E-06	flush i/o buffers

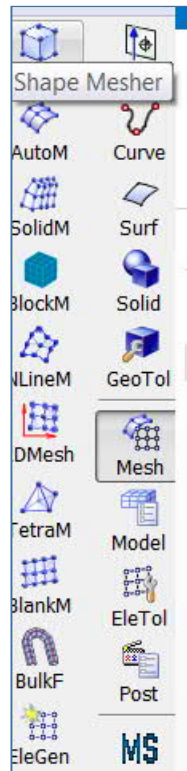
General modelling guidelines

Mesh

Keyword Manager

- For regular shape shell and solid elements, the meshed elements can be generated by “Shape Mesher”
- For irregular shape shell and solid elements, the object should be created first using the point, curve, surface tools and then using “Auto Mesher” or “Solid Mesher” to generate elements
- For beam element, a curve should be created first and then using the “Element Generation” to generate beam elements

- SECTION-Define the element type (beam, shell, solid)
- MAT-Define the material properties and constitutive model
- PART-Assign the SECTION and MAT information into different modelling elements
- CONTACT-Define the interaction between different parts
- CONSTRAINED-Define the coupling mechanism of Fluid-Structure interaction
- BOUNDARY-Define the boundary conditions
- INITIAL-Define the initial conditions
- LOAD-Define applied load (e.g., gravity)
- CONTROL-Change defaults and activate solution options

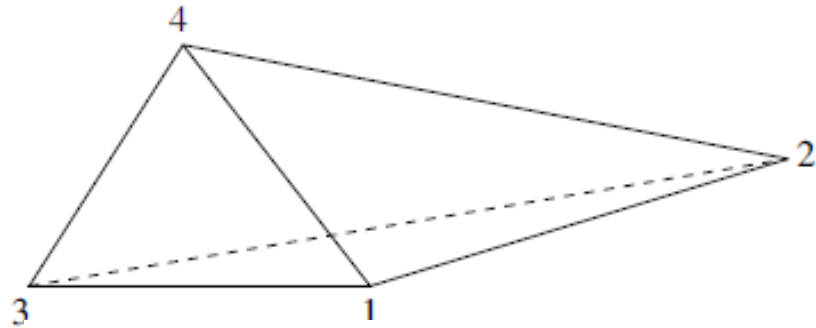


General modelling guidelines

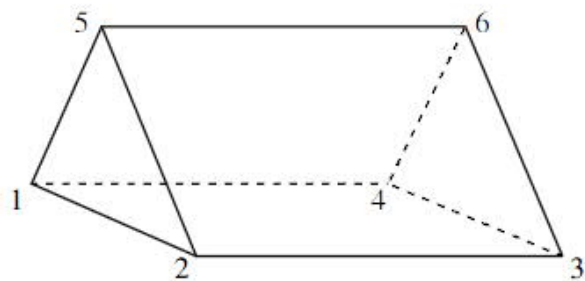
- Element type and formulation
- Material model
- Contact modelling
- Initial and boundary conditions
- Control parameters
- Unit system

Element in LS-DYNA

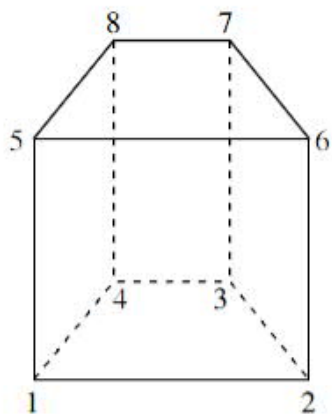
Solid elements – element shape



4-node



6-node



8-node

....

In many cases, LS-DYNA automatically generates the shape based on user defined element size and model geometry

Solid elements – element formulation

- Numerical formulation of that element

Keyword Input Form

NewID Draw RefBy Add Accept Delete Default Done

Use *Parameter Comment (Subsys: 1 sphere1.k) Setting

***SECTION_SOLID_(TITLE) (1)**

TITLE

1 SECID **ELFORM** AET

1 0 0

Repeated Data by Button and List

Data Pt.

Replace Insert

Delete Help

Repeated Data by Button and List

ELFORM:=Element formulation options:
EQ.0: 1 point corotational for *MAT_MODIFIED_HONEYCOMB,
EQ.-2: fully integrated S/R solid intended for elements with poor aspect ratio, accurate formulation.
EQ.-1: fully integrated S/R solid intended for elements with poor aspect ratio, efficient formulation.
EQ.1: constant stress solid element (default),
EQ.2: fully integrated S/R solid,

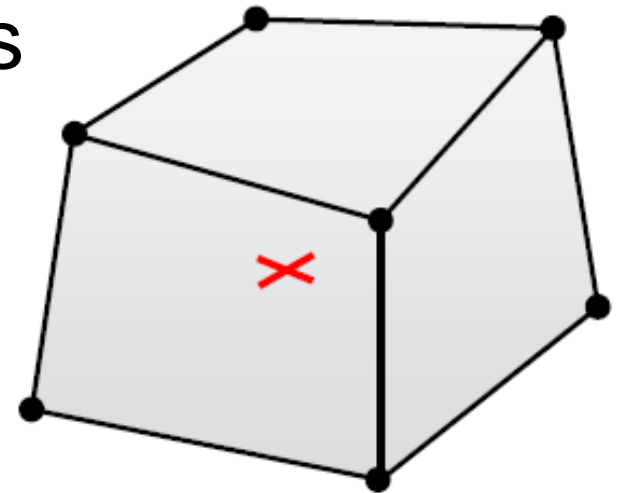
Solid element formulation options

- EQ.0: 1 point corotational for *MAT_MODIFIED_HONEYCOMB.
- EQ.1: constant stress solid element (default),
- EQ.2: fully integrated S/R solid.
- EQ.3: fully integrated quadratic 8 node element with nodal rotations,
- EQ.4: S/R quadratic tetrahedron element with nodal rotations,
- EQ.5: 1 point ALE,
- EQ.6: 1 point Eulerian,
- EQ.7: 1 point Eulerian ambient,
- EQ.8: acoustic,
- EQ.9: 1 point corotational for *MAT_MODIFIED_HONEYCOMB
- EQ.10: 1 point tetrahedron.
- EQ.11: 1 point ALE multi-material element ← Large deformation, e.g. debris
- EQ.12: 1 point integration with single material and void.
- EQ.13: 1 point nodal pressure tetrahedron for bulk forming.
- EQ.14: 8 point acoustic
- EQ.15: 2 point pentahedron element.
- EQ.18: 8 point enhanced strain solid element for linear statics only,
- EQ.31: 1 point Eulerian Navier-Stokes
- EQ.32: 8 point Eulerian Navier-Stokes

⋮

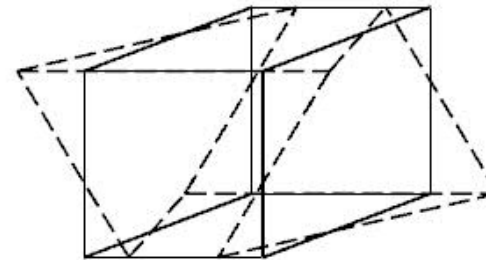
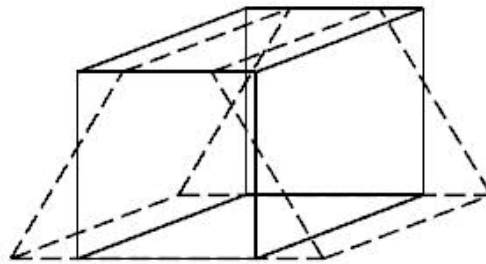
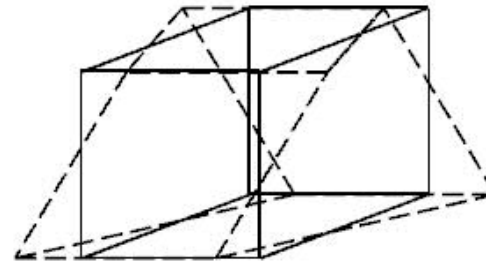
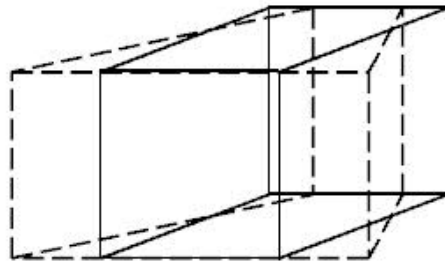
Constant stress solid element (ELFORM=1)

- Under-integrated: only ONE Gaussian point
- Efficient while less accuracy
- Even works for severe deformations
- Needs Hourglass stabilization



Hourglass

- Hourglass (HG) modes are nonphysical, zero-energy modes of deformation that produce zero strain and no stress. Hourglass modes **occur only in under-integrated** (single integration point) solid, shell, and thick shell elements.



Examples of Hourglass modes of solid element

Keywords related to Hourglass control algorithms

- Hourglass can usually be controlled by applying internal forces to resist hourglass modes via Hourglass control algorithms
- ***CONTROL_HOURLASS**
 - Sets global hourglass formulation and coefficient
- ***HOURLASS**
 - Sets hourglass formulation and coefficient for specific parts (*overrides global setting*)
- ***CONTROL_ENERGY**
 - Set HGEN to 2 to have hourglass energy calculated (**recommended**)

Takeaway recommendation

- Adopt default setting and QM (hourglass coefficient, < 0.15) for flexible barrier and debris interaction problem

Keyword Input Form

Use *Parameter Comment

(Subsys: 1 Maccaferri_RMC_160_barrier_r6.k) Setting

***HOURGLASS_(TITLE) (1)**

TITLE

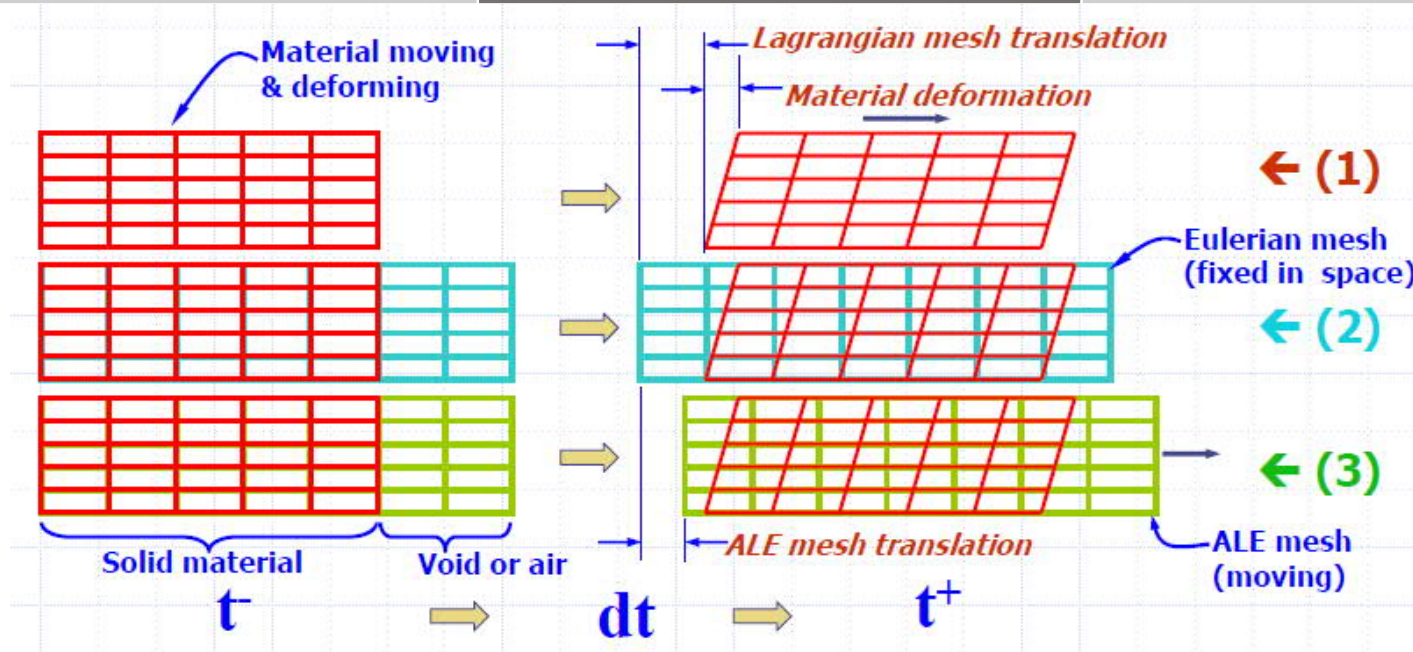
1	HGID	IHQ	QM	IBQ	Q1	Q2	QB/VDC	QW
	1	0	1.000e-06	0	0.0	0.0	0.0	0.0

COMMENT:

IHQ:=Hourglass control type. For solid elements six options are available. For quadrilateral shell and membrane elements the hourglass control is based on the formulation of Belytschko and Tsay, i.e., options 1-3 are identical, and options 4-6 are identical:
EQ.0: default=1 regardless of IHQ in *control_hourglass,
EQ.1:standard LS-DYNA viscous form,
EQ.2:Flanagan-Belytschko viscous form,
EQ.3: Flanagan-Belytschko viscous form with exact volume integration for solid elements,

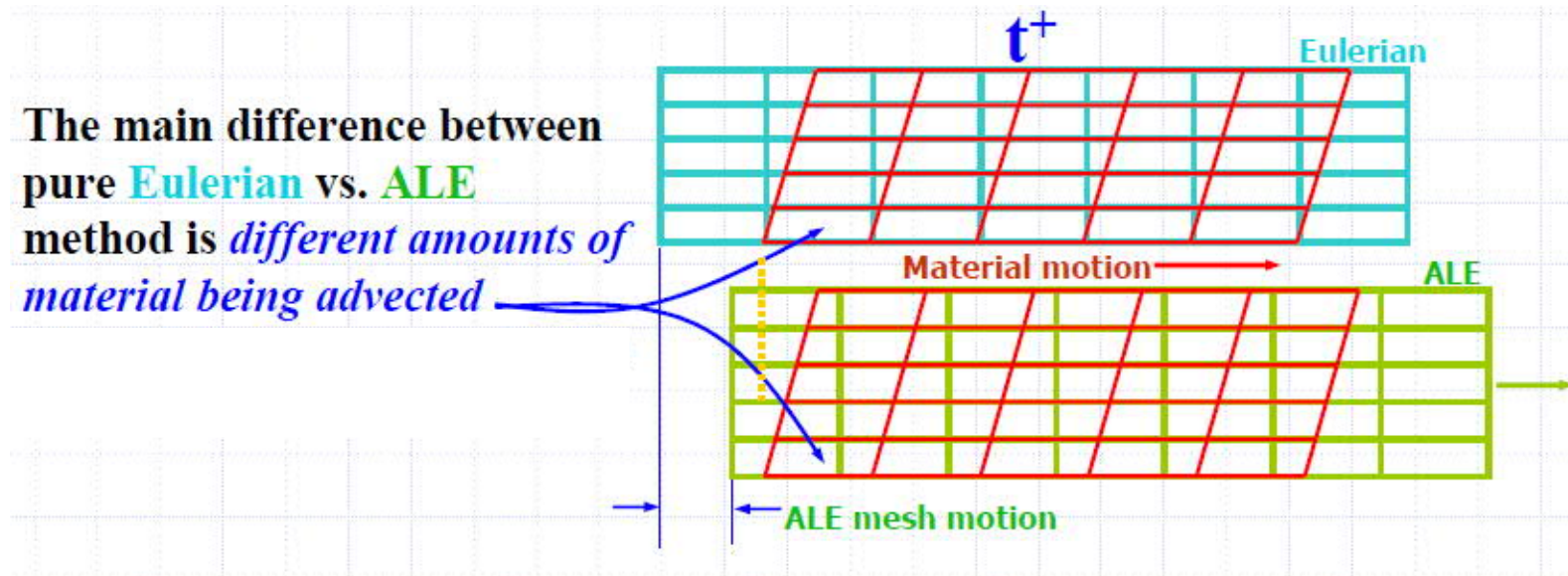
Large deformation modelling – ALE method

Finite element algorithms adopted in continuum mechanics			
Algorithms	(1) Lagrangian	(2) Eulerian	(3) Arbitrary Lagrangian–Eulerian
Description	Computational mesh moves together with the material continuum	Computational mesh is fixed and the continuum moves with respect to the grid	Both computation mesh and the material continuum can move (but not necessary together)
Example software	PLAXIS, Phase2, SAFE, FLAC, LS-DYNA	LS-DYNA	LS-DYNA



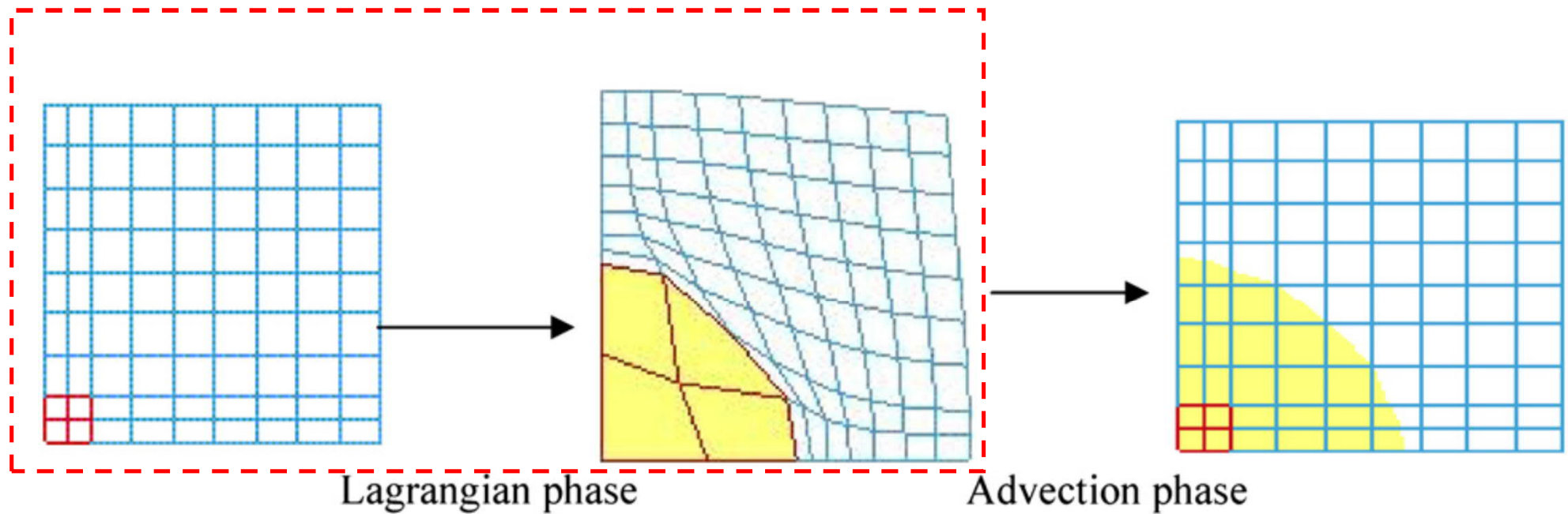
Difference between Eulerian and ALE

- Eulerian method is a subset of the ALE where the computational mesh stays fixed in space



An illustration

Conventional understanding



Element formulation for modelling debris

The image shows a screenshot of ANSYS software. In the background, a 3D model of a debris structure is visible, meshed with yellow elements. The model is titled "RMC160DF_6m/s_150m3". A tree view on the left shows the assembly structure, including "FEM Parts" and "Debris".

In the foreground, the "Keyword Input Form" dialog box is open. It contains the following information:

- Buttons: NewID, Draw, RefBy, Add, Accept, Delete, Default, Done, Setting.
- Options: Use *Parameter, Comment.
- Subsys: 1 Maccaferri_RMC_160_barrier_r6.k
- Title: *SECTION_SOLID_(TITLE) (2)
- Section Name: Debris
- Table:

SECID	ELFORM	AET
1	11	4
- Buttons: Repeated Data by Button and List, Data Pt., Replace, Insert, Delete, Help.
- Legend:
 - EQ.6: 1 point Eulerian,
 - EQ.7: 1 point Eulerian ambient, EQ.8: acoustic,
 - EQ.9: 1 point corotational for *MAT_MODIFIED_HONEYCOMB,
 - EQ.10: 1 point tetrahedron,
 - EQ.11: 1 point ALE multi-material element, (highlighted)
 - EQ.12: 1 point integration with single material and void,

In the background, the "Keyword Manager" window is also visible, showing a list of keywords and their counts:

Name	Count
ALE	2
MULTI-MATERIAL_GROUP	2
BOUNDARY	4
CHANGE	3
CONSTRAINED	3
	1
	2
	3
	1
	1
	1
	1
	3
	95603
	1
	1
	1
	1
	8
	111960
	11
	11
	9
	5
	2
	2
	5
	1

Keyword used together with ELFORM=11

- ***ALE_MULTI-MATERIAL_GROUP (AMMG)**

The screenshot displays the ANSYS software interface for defining a keyword. The main window shows a 3D model of a debris structure with a yellow mesh, labeled "Debris AMMG". The "Keyword Input Form" window is open, showing the following configuration:

- NewID:** 4
- Use *Parameter:**
- Comment:**
- IDTYPE:** 1
- GPNAME:** Debris
- Keyword:** *ALE_MULTI-MATERIAL_GROUP (2)

The "Link PART" dialog is also open, showing a list of parts. The "Debris" part is selected, and it is highlighted with a red circle and labeled "Solid material".

The "Keyword Manager" window in the background shows a list of keywords with their counts:

Name	Count
ALE	2
MULTI-MATERIAL_GROUP	2
...	...

Air / void AMMG

RMC160DF_8m/s_150m3

- Assembly 1
 - FEM Parts
 - 1 Topo_bottom
 - 2 Topo_side
 - 3 Container
 - 4 Debris
 - 5 Horizontal cable
 - 6 Brake element
 - 7 Side cable
 - 8 Ring 1
 - 9 Ring 2
 - 10 Shackle
 - 11 Null membrane
 - Keyword Entity
 - Boundary
 - Contact
 - Define
 - Load
 - Set

Keyword Input Form

NewID: 1, 2

Use *Parameter: Comment: (Subsys: 1 Maccaferri_160_8ms.k) Setting

*ALE_MULTI-MATERIAL_GROUP (2)

SID	IDTYPE	GPNAME
3	1	Air

Link PART

- PART
- 1 Topo_bottom
- 2 Topo_side
- 3 Container
- 4 Debris
- 5 Horizontal cable
- 6 Brake element
- 7 Side cable
- 8 Ring 1
- 9 Ring 2
- 10 Shackle

Air / void material

Material List

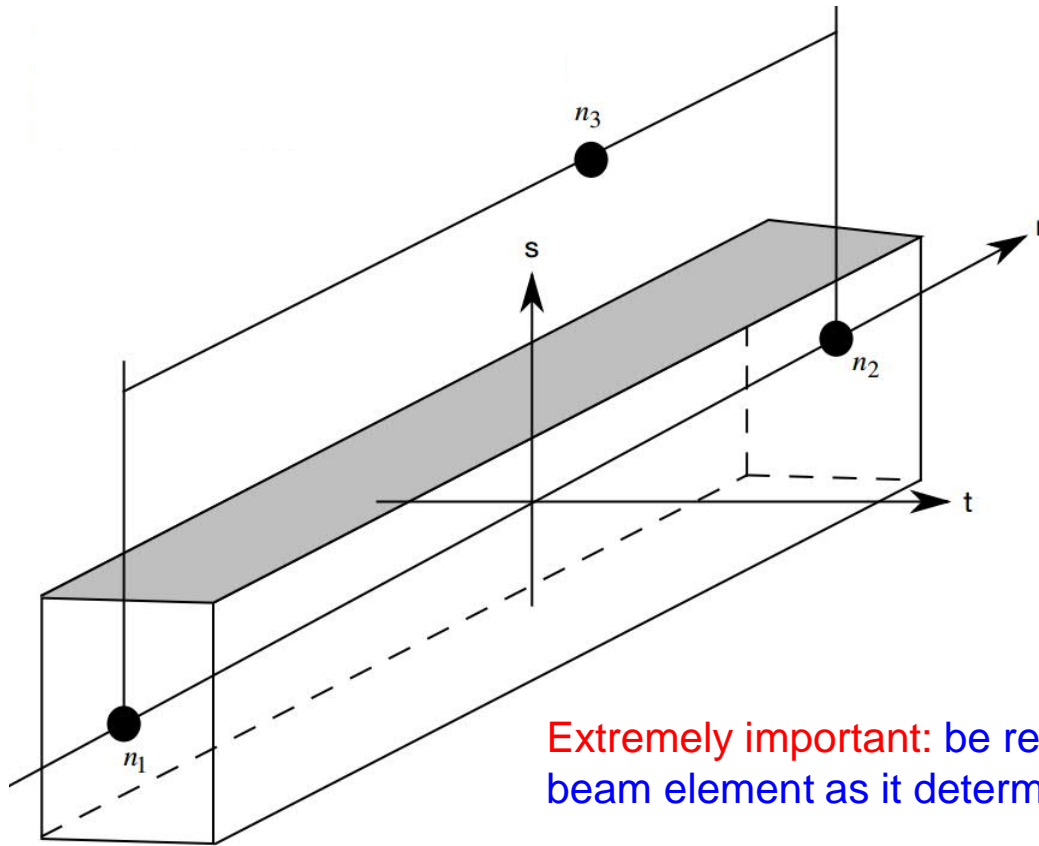
Name	Count
ALE	2
MULTI-MATERIAL_GROUP	2
BOUNDARY	4
CHANGE	3
CONSTRAINED	3
CONTACT	1
CONTROL	3
DATABASE	3
DEFINE	3
ELEMENT	95603
HOURLASS	1
KEYWORD	1
LOAD	1
MAT	8
NODE	111960
PART	11
PART	11
SECTION	9
SET	5
TITLE	1

Material arrange: GroupBy: Model, Sort: Type, List: All

Model Check, Keyword Del, ResForm, ExpandAll, CollapseAll

Beam elements

- All structures components of a flexible barrier are modelled by beam elements



Extremely important: be reminded to define Node n_3 when generating beam element as it determines the initial orientation of the cross section!!!

Element formulation for beam elements

- Recommended type ELFORM=1 OR 2

RMC160DF_6m/s_150m3

Assembly 1
FEM Parts
Keyword Entity
Boundary
Contact
Define
Load
Set

Keyword Input Form

NewID Draw RefBy Pick Add Accept Delete Default Done

Use *Parameter Comment (Subsys: 1 Maccaferri_RMC_160_barrier_r6.k) Setting

*SECTION_BEAM_(TITLE) (5)

TITLE
Shackle

Resultant Beam Shape Definition

1	SECID	ELFORM	SHRF	QR/IRID	CST	SCoor	NSM
	14	1	0.0	0	1	0.0	0.0

2	TS1	TS2	TI1	TI2	NSLOC	NTLOC
	0.0200000	0.0200000	0.0	0.0	0.0	0.0

COMMENT:
ELFORM:=Element formulation options:
EQ.1: Hughes-Liu with cross section integration (default),
EQ.2: Belytschko-Schwer resultant beam (resultant),
EQ.3: truss (resultant),

10 Ring
11 Horizontal cable
12 Side cable
13 Brake element
14 Shackle

Edt: SECTION_BEAM Edit RefBy

Model All

Name	Count
ALE	2
BOUNDARY	4
CHANGE	3
CONSTRAINED	3
CONTACT	1
CONTROL	2
DATABASE	3
DEFINE	3
ELEMENT	95603
HOURLGLASS	1
KEYWORD	1
LOAD	1
MAT	8
NODE	111960
PART	11
SECTION	9
BEAM	5
SHELL	2
SOLID	2
SET	5
TITLE	1

Material arrange
GroupBy Sort List
Model Type All
Load From MatDB
Model Check Keyword Del ResForm

ELFORM= 2

RMC160DF_6m/s_150m3

- >
- Assembly 1
 - FEM Parts
 - Keyword Entity
 - Boundary
 - Contact
 - Define
 - Load
 - Set

Keyword Input Form

NewID Draw RefBy Pick Add Accept Delete Default Done

Use *Parameter Comment (Subsys: 1 Maccaferri_RMC_160_barrier_r6.k) Setting

***SECTION_BEAM_(TITLE) (5)**

TITLE
Ring

Resultant Beam Shape Definition

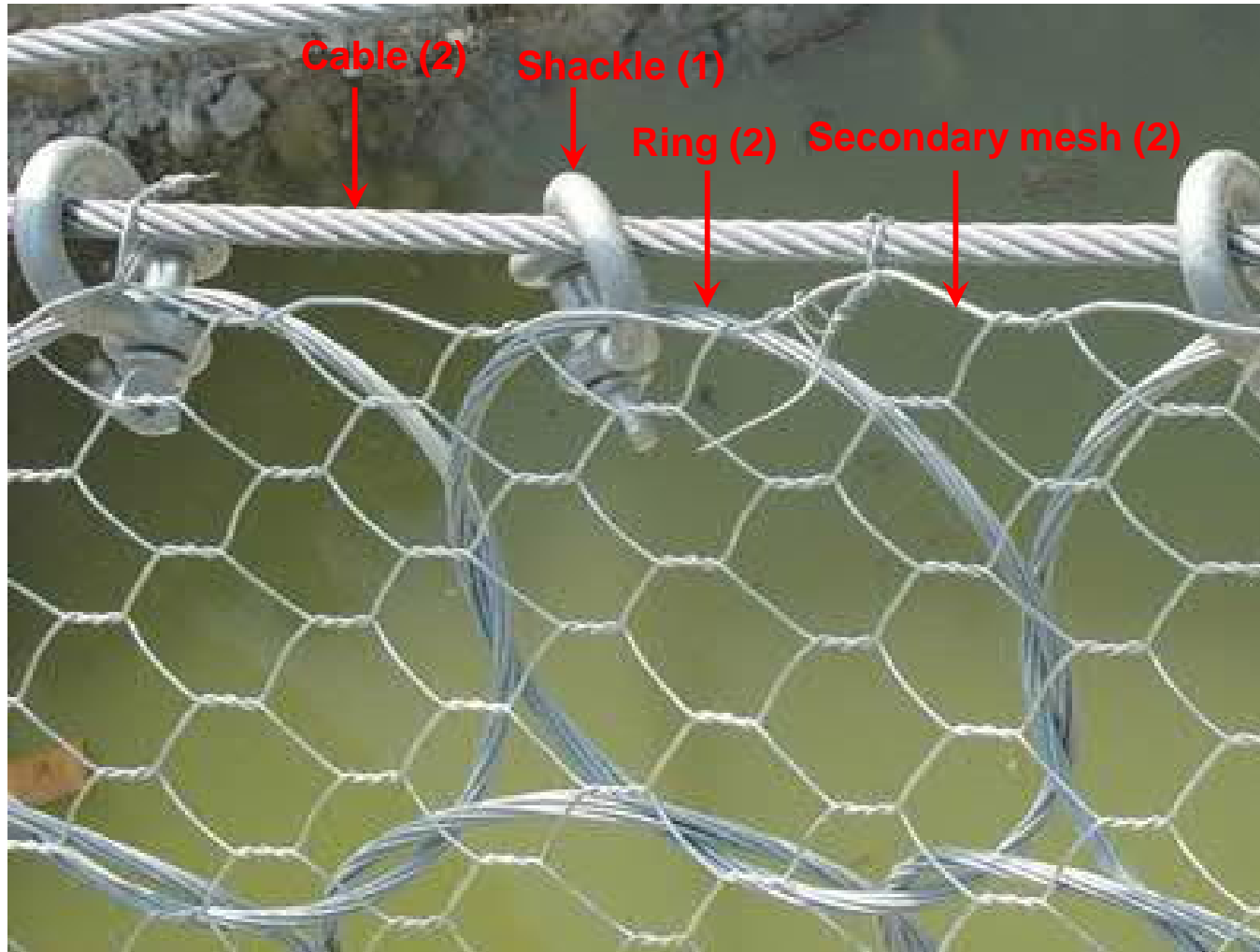
1	<u>SECID</u>	<u>ELFORM</u>	<u>SHRF</u>	<u>QR/IRID</u>	<u>CST</u>	<u>SCOOR</u>	<u>NSM</u>
	10	2	0.0	0	0	0.0	0.0
2	<u>A</u>	<u>ISS</u>	<u>ITI</u>	<u>J</u>	<u>SA</u>	<u>IST</u>	
	8.478e-05	4.770e-11	4.770e-11	9.600e-11	8.478e-05	0.0	

COMMENT:

ELFORM:=Element formulation options:
EQ.1: Hughes-Liu with cross section integration (default),
EQ.2: Belytschko-Schwer resultant beam (resultant),
EQ.3: truss (resultant),

10 Ring
11 Horizontal cable
12 Side cable
13 Brake element
14 Shackle

ELFORM=1 OR 2, which to choose – Example



Shell elements

- Used for modelling thin structures, e.g. topography surface, membrane etc.

RMC160DF_6m/s_150m3

Assembly 1
FEM Parts
Keyword Entity
Boundary
Contact
Define
Load
Set

Keyword Input Form

RefBy Sort/T1 Add Accept Delete Default Done

3 Topo
9 Null membrane

Use *Parameter Comment (Subsys: 1 Maccaferri_RMC_160_barrier_r6.k) Setting

*SECTION_SHELL_(TITLE) (2)

TITLE
Topo

SECID	ELFORM	SHRF	NIP	PROPT	QR/IRID	ICOMP	SETYP
3	2	0.0	0	1	0	0	1

T1	T2	T3	T4	NLOC	MAREA	IDOF	EDGSET
0.0050000	0.0050000	0.0050000	0.0050000	0.0	0.0	0.0	0

Repeated Data by Button and List

Data Pt.
Replace Insert
Delete Help

ELFORM:=ELFORM Element formulation options:
EQ.1: Hughes-Liu,
EQ.2: Belytschko-Tsay (default),

Edit: SECTION_SHELL Edit RefBy

Model All

Name	Count
ALE	2
BOUNDARY	4
CHANGE	3
CONSTRAINED	3
CONTACT	1
CONTROL	2
DATABASE	3
DEFINE	3
ELEMENT	95603
HOURGLASS	1
KEYWORD	1
LOAD	1
MAT	8
NODE	111960
PART	11
SECTION	9
BEAM	5
SHELL	2
SOLID	2
SET	5
TITLE	1

Material arrange

Shell element formulation options

Shell Element formulation options

EQ.1: Hughes-Liu,

EQ.2: Belytschko-Tsay,

EQ.3: BCIZ triangular shell,

EQ.4: C₀ triangular shell,

EQ.5: Belytschko-Tsay membrane,

EQ.6: S/R Hughes-Liu ,

EQ.7: S/R co-rotational Hughes-Liu,

EQ.8: Belytschko-Leviathan shell ,

EQ.9: Fully integrated Belytschko-Tsay membrane,

EQ.10: Belytschko-Wong-Chiang,

EQ.11: Fast (co-rotational) Hughes-Liu,

EQ.12: Plane stress (x-y plane) ,

EQ.13: Plane strain (x-y plane)

EQ.14: Axisymmetric solid (y-axis of symmetry) - area weighted,

EQ.15: Axisymmetric solid (y-axis of symmetry) - volume weighted,

EQ.16: Fully integrated shell element (very fast),

EQ.17: Fully integrated DKT, triangular shell element ,

EQ.18: Fully integrated linear DK quadrilateral/triangular shell

EQ.20: Fully integrated linear assumed strain C₀ shell

EQ.31: 1 point Eulerian Navier-Stokes

EQ.32: 8 point Eulerian Navier-Stokes

Default element formulation, good for most cases except when excessive wrapping is anticipated

Material models

Material models

- Provide more than 200 materials models for users
- Defined under keyword ***MAT**
- Classification of material models
 - Elastic
 - Elastic-plastic
 - Viscoelastic
 - ...
- Naming is different from what we are familiar with (Mohr-Coulomb, Modified Cam-clay, hardening soil etc.)

Example – Elastic (MAT001)

The screenshot shows the 'Keyword Input Form' window for LS-DYNA. The title bar reads 'Keyword Input Form'. The window contains several sections:

- Buttons:** NewID, MatDB, RefBy, Pick, Add, Accept, Delete, Default, Done, Setting.
- Options:** Use *Parameter, Comment.
- Subsystem:** (Subsys: 1 Maccaferri_RMC_160_barrier_r6.k)
- Material Definition:** *MAT_ELASTIC_(TITLE) (001) (3)
- TITLE:** Ring
- Material Properties Table:**

1	MID	RO	E	PR	DA	DB	NOT USED
	9	7800.0000	2.000e+11	0.3000000	0.0	0.0	0

COMMENT:

E:=Young's modulus.

Material List:

- 9 Ring
- 10 Shackle
- 11 Cable

Material Selection Tree:

- INTEGRATION
- INTERFACE
- KEYWORD 1
- LOAD 1
- LSO
- MAT 8
 - 000-ADD_COHESIVE
 - 000-ADD_EROSION
 - 000-ADD_FATIGUE
 - 000-ADD_GENERALIZED_DAMAGE
 - 000-ADD_PERMEABILITY
 - 000-ADD_PORE_AIR
 - 000-ADD_THERMAL_EXPANSION
 - 000-NONLOCAL
 - 000-ELASTIC_PERI
 - 001-ELASTIC 3**
 - 001_FLUID-ELASTIC_FLUID
 - 002-ORTHOTROPIC_ELASTIC
 - 002_ANIS-ANISOTROPIC_ELASTIC
 - 002_SUNIL-COMPOSITE_FAILURE_SUNIL
 - 003-PLASTIC_KINEMATIC

- LS-DYNA Manual: Volume II
- LS-DYNA theory manual

Material model – debris (MAT005)

Keyword Input Form

NewID 1 Debris

Use *Parameter Comment (Subsys: 1 Maccaferri_RMC_160_barrier_r6.k)

*MAT_SOIL_AND_FOAM,(TITLE) (005) (1)

TITLE
Debris

1	MID	RO	G	BULK	A0	A1	A2	PC
	1	2200.0000	5.000e+05	1.000e+06	0.0100000	0.0	0.0670000	-1.000e+08
2	VCR	REF	LCID					
	1.0	0.0	0					
3	EPS1	EPS2	EPS3	EPS4	EPS5	EPS6	EPS7	EPS8
	0.0	1.0000000	0.0	0.0	0.0	0.0	0.0	0.0
4	EPS9	EPS10						
	0.0	0.0						
5	P1	P2	P3	P4	P5	P6	P7	P8
	0.0	1.000e+06	0.0	0.0	0.0	0.0	0.0	0.0
6	P9	P10						
	0.0	0.0						

COMMENT:

Total Card: 1 Smallest ID: 1 Largest ID: 1 Total deleted card: 0

Name Count

- 001-ELASTIC 3
- 001-FLUID-ELASTIC_FLUID
- 002-ORTHOTROPIC_ELASTIC
- 002-ANIS-ANISOTROPIC_ELASTIC
- 002-SUNIL-COMPOSITE_FAILURE_SUNIL
- 003-PLASTIC_KINEMATIC
- 004-ELASTIC_PLASTIC_THERMAL
- 005-SOIL_AND_FOAM 1
- 006-VISCOELASTIC
- 007-BLATZ-KO_RUBBER
- 008-HIGH_EXPLOSIVE_BURN
- 009-NULL 1
- 010-ELASTIC_PLASTIC_HYDRO
- 010-ELASTIC_PLASTIC_HYDRO_STOCHA:
- 010-SPALL-ELASTIC_PLASTIC_HYDRO_SF
- 011-STEINBERG
- 011-LUND-STEINBERG_LUND
- 012-ISOTROPIC_ELASTIC_PLASTIC
- 013-ISOTROPIC_ELASTIC_FAILURE
- 014-SOIL_AND_FOAM_FAILURE
- 015-JOHNSON_COOK
- 015-JOHNSON_COOK_STOCHASTIC
- 016-PSEUDO_TENSOR
- 017-ORIENTED_CRACK
- 018-POWER_LAW_PLASTICITY

Material arrange

GroupBy Sort List

All Type All

- **Drucker – Prager** model (elastoplastic model)
- Parameter input: NO conventional concept of cohesion, frictional angle

Key input parameters of Drucker – Prager model

$$A_2 = \left(\frac{-\sin\phi'}{\cos\theta - \left(\frac{1}{\sqrt{3}}\right)\sin\theta\sin\phi'} \right)^2$$

$$A_1 = \frac{-\sin\phi'}{\cos\theta - \left(\frac{1}{\sqrt{3}}\right)\sin\theta\sin\phi'} \times \frac{-c\cos\phi'}{\cos\theta - \left(\frac{1}{\sqrt{3}}\right)\sin\theta\sin\phi'}$$

$$A_0 = \left(\frac{-c\cos\phi'}{\cos\theta - \left(\frac{1}{\sqrt{3}}\right)\sin\theta\sin\phi'} \right)^2$$

c : cohesion

ϕ' : internal friction angle

θ : Lode Angle, usually assume = 0

Material model – MAT_RIGID(MAT020)

- Topography
- Boulders

Keyword Input Form

NewID Use *Parameter Comment

MatDB RefBy Pick Add Accept Delete Default Done

(Subsys: 1 Maccaferri_RMC_160_barrier_r6.k) Setting

*MAT_RIGID_(TITLE) (020) (1)

TITLE
Topo

1	<u>MID</u>	<u>RO</u>	<u>E</u>	<u>PR</u>	<u>N</u>	<u>COUPLE</u>	<u>M</u>	<u>ALIAS</u>
	2	2500.0000	1.000e+07	0.3000000	0.0	0	0.0	

2	<u>CMO</u>	<u>CON1</u>	<u>CON2</u>
	1.0	7	7

3	<u>LCO OR A1</u>	<u>A2</u>	<u>A3</u>	<u>V1</u>	<u>V2</u>	<u>V3</u>
	0.0	0.0	0.0	0.0	0.0	0.0

COMMENT:

Total Card: 1 Smallest ID: 2 Largest ID: 2 Total deleted card: 0

2 Topo

- 000-VISCOELASTIC
- 007-BLATZ-KO_RUBBER
- 008-HIGH_EXPLOSIVE_BURN
- 009-NULL
- 010-ELASTIC_PLASTIC_HYDRO
- 010-ELASTIC_PLASTIC_HYDRO_STOCHA:
- 010_SPALL-ELASTIC_PLASTIC_HYDRO_SF
- 011-STEINBERG
- 011_LUND-STEINBERG_LUND
- 012-ISOTROPIC_ELASTIC_PLASTIC
- 013-ISOTROPIC_ELASTIC_FAILURE
- 014-SOIL_AND_FOAM_FAILURE
- 015-JOHNSON_COOK
- 015-JOHNSON_COOK_STOCHASTIC
- 016-PSEUDO_TENSOR
- 017-ORIENTED_CRACK
- 018-POWER_LAW_PLASTICITY
- 019-STRAIN_RATE_DEPENDENT_PLASTI
- 020-RIGID
- 021-ORTHOTROPIC_THERMAL
- 022-COMPOSITE_DAMAGE
- 023-TEMPERATURE_DEPENDENT_ORTH
- 024-PIECEWISE_LINEAR_PLASTICITY
- 024-PIECEWISE_LINEAR_PLASTICITY_HA:

Material arrange

Material model – cables, post, rings and shackles etc.

- A couple of choices exist
 - Elastic only (MAT001)
 - Elastic-plastic (MAT003)

The screenshot shows the 'Keyword Input Form' for defining a material model. The form includes a 'NewID' button, checkboxes for 'Use *Parameter' and 'Comment', and a 'Setting' button. The current material is identified as '*MAT_PLASTIC_KINEMATIC_(TITLE) (003) (0)'. The input fields are as follows:

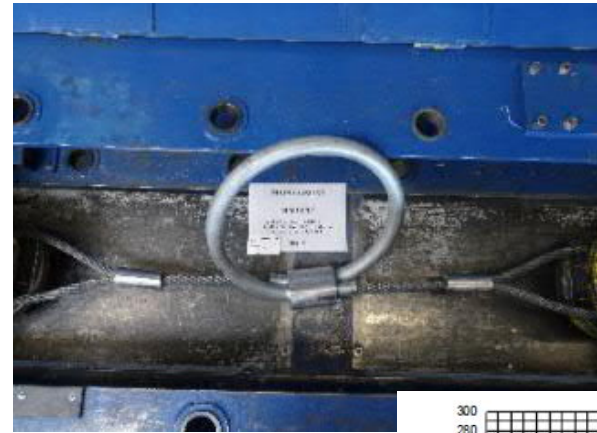
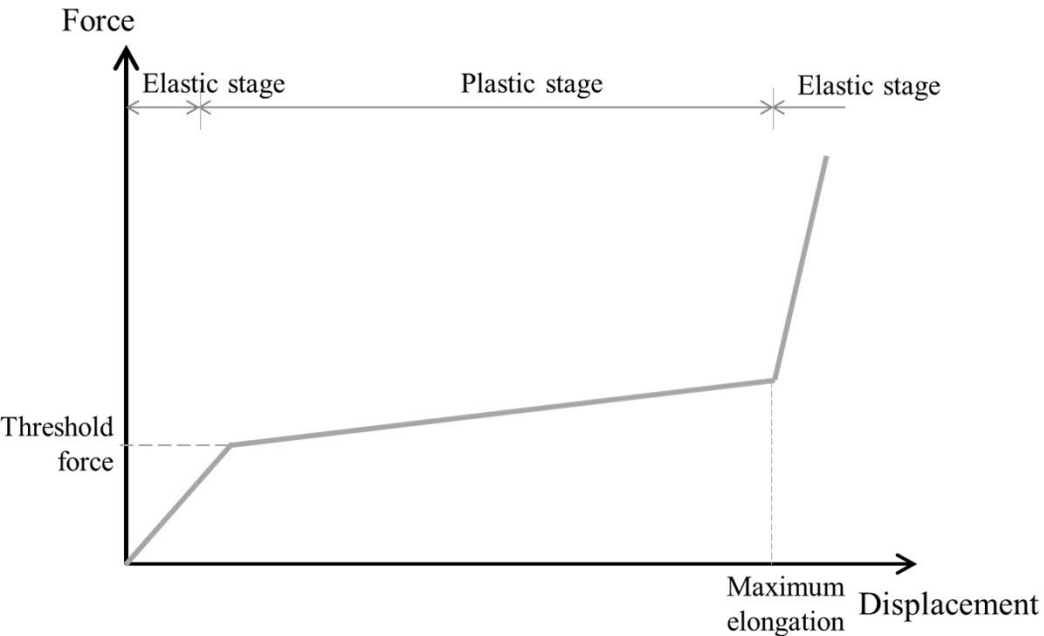
TITLE							
1	MID	RO	E	PR	SIGY	ETAN	BETA
						0.0	0.0
2	SRC	SRP	FS	VP			
	0.0	0.0	0.0	0.0			

COMMENT:
SIGY:=Yield stress.

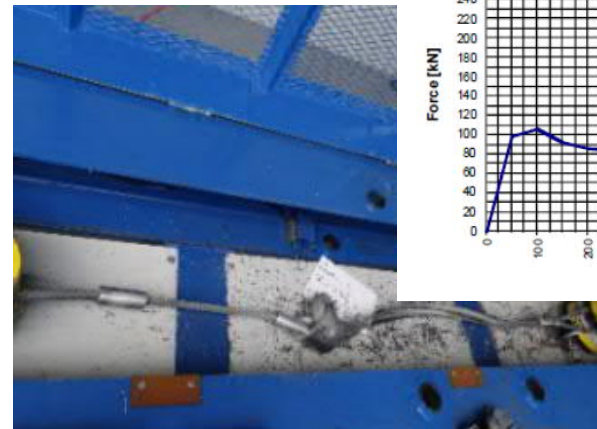
On the right side, a list of material models is visible, with '003-PLASTIC_KINEMATIC' highlighted in yellow. Other models include 000-ADD_THERMAL_EXPANSION, 000-NONLOCAL, 000-ELASTIC_PERI, 001-ELASTIC, 001-FLUID-ELASTIC_FLUID, 002-ORTHOTROPIC_ELASTIC, 002_ANIS-ANISOTROPIC_ELASTIC, 002_SUNIL-COMPOSITE_FAILURE_SUNIL, 004-ELASTIC_PLASTIC_THERMAL, 005-SOIL_AND_FOAM, 006-VISCOELASTIC, 007-BLATZ-KO_RUBBER, 008-HIGH_EXPLOSIVE_BURN, 009-NULL, 010-ELASTIC_PLASTIC_HYDRO, 010-ELASTIC_PLASTIC_HYDRO_STOCHA, 010_SPALL-ELASTIC_PLASTIC_HYDRO_SF, and 011-STEINBERG.

Material model – brake elements

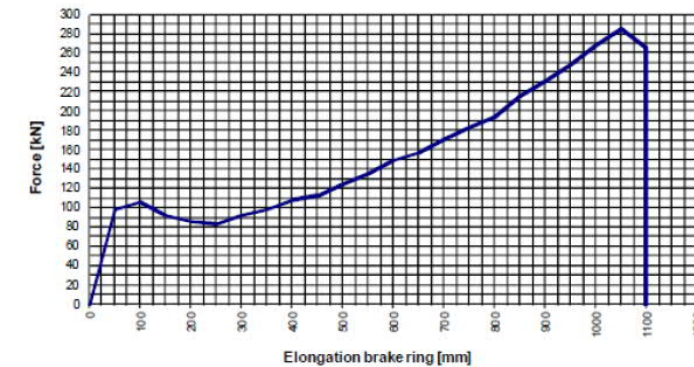
Working principles



Before test



After test



- Possible choices: e.g. **MAT094** (Inelastic_Spring_Discrete_Beam), **MAT003**
- Other options are encouraged as long as justification is made

Contact modelling

Types of contact

- Purpose of contact: allow different parts interact with each other and thus load transfer occurs
- Typically used:
 - *Surface to surface*, e.g. boulder & topography
 - *Node to surface*, e.g. boulder & flexible barrier
 - *Single surface*, e.g. components of flexible barrier
 - ...

Contact input card

Keyword Input Form

NewID Draw Pick Add Accept Delete Default Done 1 (1)

Use *Parameter Comment (Subsys: 1 Maccaferri_160_8ms.k) Setting

*CONTACT_AUTOMATIC_GENERAL_(ID/TITLE/MPP) (1)

1	CID	TITLE						
1	1							
			<input type="checkbox"/> MPP1	<input type="checkbox"/> MPP2				
2	IGNORE	BUCKET	LCBUCKET	NS2TRACK	INITITER	PARMAX	UNUSED	CPARM8
		200		3	2	1.0005		0
3	UNUSED	CHKSEGS	PENSF	GRPABLE				
		0		0				
4	SSID	MSID	SSTYP	MSTYP	SBOXID	MBOXID	SPR	MPR
	2	0	2	0	0	0	0	1
5	FS	FD	DC	VC	VDC	PENCHK	BT	DT
	0.1000000	0.1000000	0.0	0.0	0.0	0	0.0	1.000e+10
6	SFS	SFM	SFT	SFT	SFST	SFMT	FSF	VSF
	1.0000000	1.0000000	0.0	0.0	1.0000000	1.0000000	1.0000000	1.0000000
			<input type="checkbox"/> A	<input type="checkbox"/> AB	<input checked="" type="checkbox"/> ABC	<input type="checkbox"/> ABCD	<input type="checkbox"/> ABCDE	<input type="checkbox"/> ABCDEF
7	SOFT	SOFSC	LCIDAB	MAXPAR	SBOPT	DEPTH	BSORT	FRCFRQ
	1	0.0010000	0	0.0	0.0	0	0	0
8	PENMAX	THKOPT	SHLTHK	SNLOG	ISYM	I2D3D	SLDTHK	SLDSTE
	0.0	0	0	0	0	0	0.0	0.0
9	IGAP	IGNORE	DPRFAC/MPAR1	DTSTIF/MPAR2	UNUSED	UNUSED	FLANGL	CID_RCF
	0	1	0.0	0.0	0	0	0.0	0
10	Q2TRI	DTPCHK	SFNBR	FNLSCL	DNLSCL	TCSO	TIEDID	SHLEDG

EQ:0: penalty formulation,
EQ:1: soft constraint formulation,
EQ:2: pinball segment based contact.
EQ:4: constraint approach for FORMING contact option.

Identification of slave

Identification of master

Frictional coefficient

Dynamic Frictional coefficient

Contact stiffness

Contact force calculating method

- Most commonly used: penalty-based
 - Normal direction resist penetration: **contact stiffness**
 - Tangent direction resist friction: frictional coefficient

Contact Stiffness: SOFT=0

- Default contact stiffness k is prescribed as follows for a solid element:

$$k = \frac{\alpha KA^2}{V}$$

K is the material bulk modulus
 α is the penalty scale factor
 A is the segment area
 V is the element volume

- For a shell element:

$$k = \frac{\alpha KA}{\text{Max shell diagonal}}$$

Contact Stiffness: SOFT=1

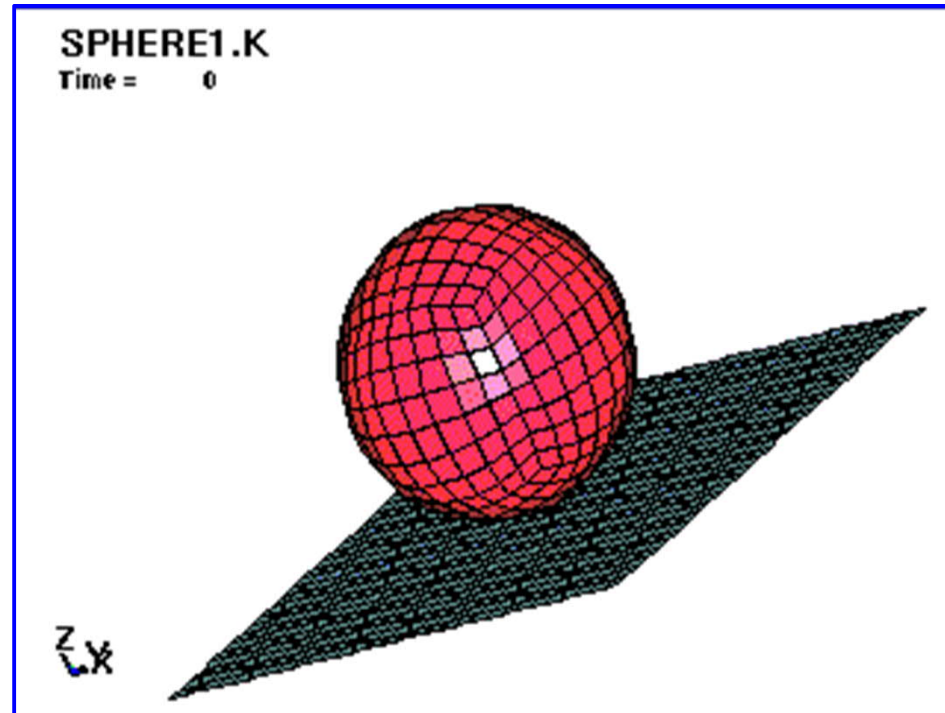
- SOFT parameter is prescribed on Opt. Card A of *CONTACT
- SOFT=1 contact stiffness is maximum of ...
 - The SOFT=0 stiffness (see previous page), and
 - A stiffness calculated based on stability of a spring-mass system considering...
 - Nodal masses
 - Global timestep, Δt

$$k = \text{SOFSCCL} \frac{m}{\Delta t^2}$$

- SOFT=1 is usually recommended for contact involving soft materials, e.g., foams, or for contact between parts of dissimilar mesh densities

Surface to surface contact

- Utilize two-way treatment: master\slave distinction not important

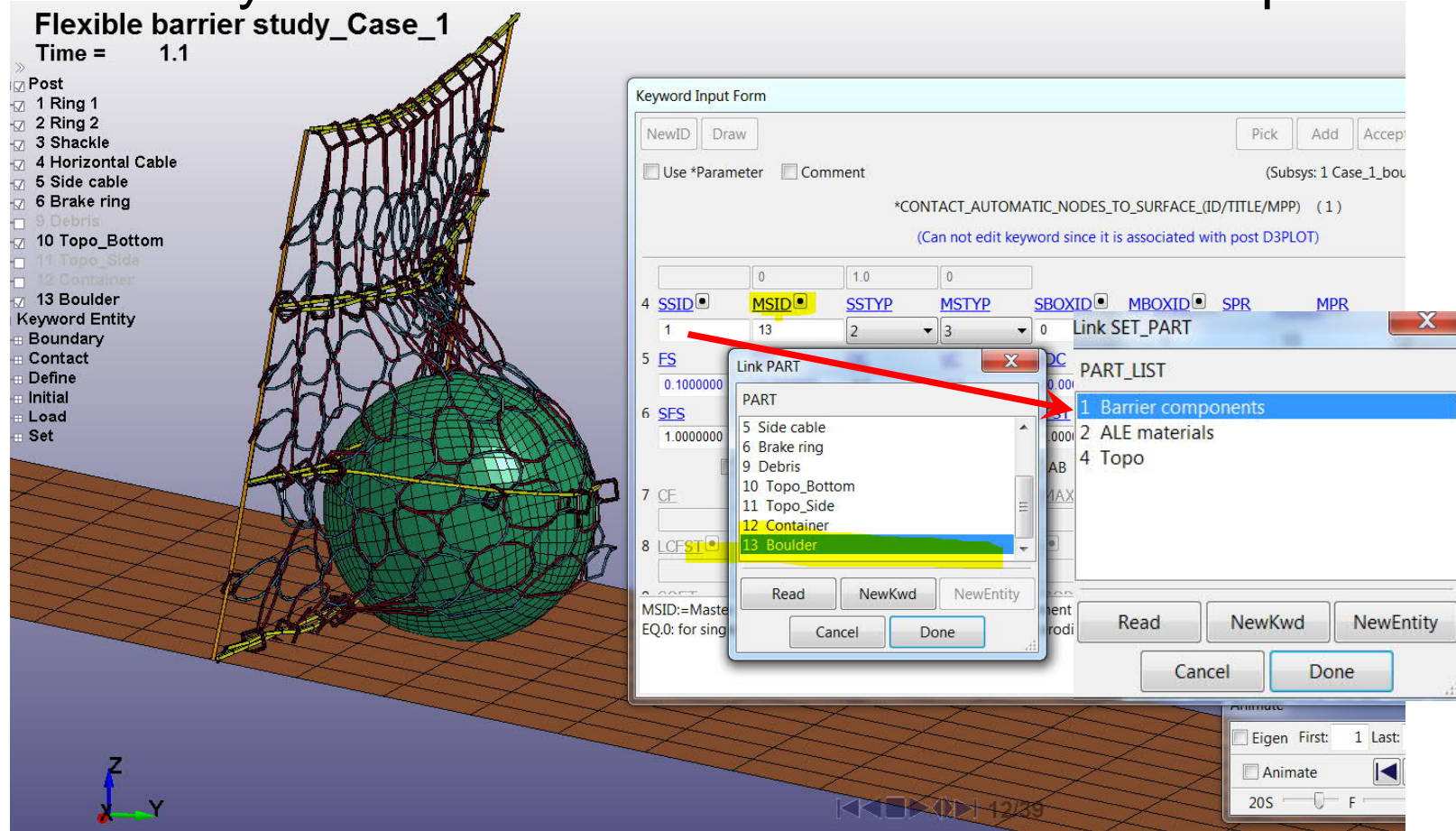


Automatic surface to surface

- Efficient and robust penetration searching method

Nodes to surface contact

- Utilize one-way treatment: master\slave distinction important



Automatic nodes to surface

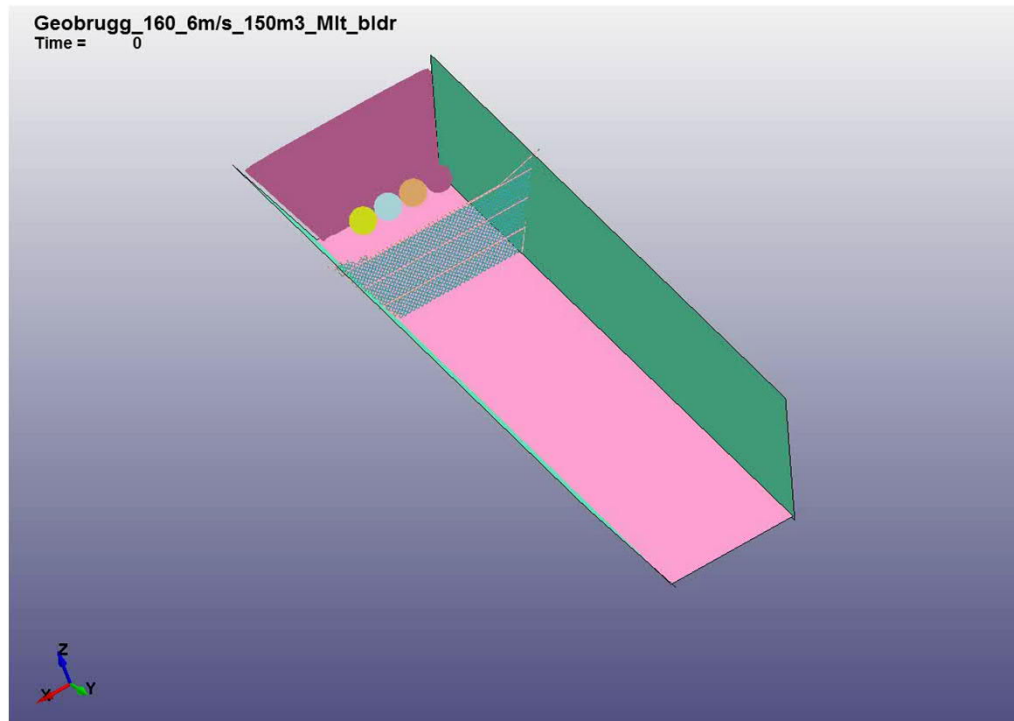
- Efficient and robust penetration searching method

Single surface contact

- Concept of single surface contact
 - Assumes that everything contacts everything else
 - *Automatic_general*
 - Computationally expensive but very robust
 - *Single-surface* formulation and only the slave side is defined
 - Good for edge-to-edge, beam-to-beam contact (e.g. flexible barrier components)
 - *Automatic_single_surface*
 - less CPU expensive form of *Automatic_general*
 - Most common contact used in impact simulation

ALE contact with *Lagrangian*

- *Constraint_Lagrange_In_Solid*
 - Generate forces that resist penetration of the ALE through the Lagrangian parts



Constraint_Lagrange_In_Solid

keywora input form

NewID

Use *Parameter Comment

(Subsys: 1 Geobrugg_160_Mlt_bldr.k) Setting

*CONSTRAINED_LAGRANGE_IN_SOLID (4)

1	COUPID	TITLE						
1		Topobottominair						
2	SLAVE	MASTER	SSTYP	MSTYP	NQUAD	CTYPE	DIREC	MCOUP
1	1	1	1	0	3	4	2	1
3	START	END	PFAC	FRIC	FRCMIN	NORM	NORMTYP	DAMP
0.0	1.000e+10	0.0	0.2250000	0.0100000	0	1	0.0	0.0
4	CQ	HMIN	HMAX	ILEAK	PLEAK	LCIDPOR	NVENT	BLOCKAGE
0.0	0.0	0.0	0	0.1000000	0	0	0	0
5	IBOXID	IPENCHK	INTFORC	IALESOF	LAGMUL	PFACMM	THKF	
0	0	0	0	0.0	0	0.0	0.0	

Repeated Data by Button and List

VENTSID	VENTYP	VTCOEF	POPPRES	COEFLC
0	0	0.0	0.0	0

Data Pt.

Replace Insert

Delete Help

COMMENT:

MCOUP:=Multi-material option (CTYPE 4 and 5).
 EQ.0: couple with all multi-material groups,
 EQ.1: couple with material with highest density.

Good practices:

CTYPE : coupling method, Chose 4 (penalty coupling)

DIREC: coupling direction, Chose 2 (normal direction)

MCOUP: couple with which multi-material group

FRIC: friction coefficient, calculated from friction angle

Initial and boundary conditions

Initial conditions

Keyword	Operation object	Rotational velocity	Translational velocity	Remark
<i>Initial_Velocity_Generation</i>	Part or node set	√	√	Must not be used with *Initial_velocity
<i>Initial_Velocity_Rigid_Body</i>	Rigid Part			e.g. boulder
<i>Initial_Velocity</i>	Node set			e.g. define nodes of boulder as a set

***INITIAL_VELOCITY_GENERATION (1)**

1	<u>NSID/PID</u>	<u>STYP</u>	<u>OMEGA</u>	<u>VX</u>	<u>VY</u>	<u>VZ</u>	<u>IVATN</u>	<u>ICID</u>
		2	0.0	0.0	0.0	-89.000000	0	0
2	<u>XC</u>	<u>YC</u>	<u>ZC</u>	<u>NX</u>	<u>NY</u>	<u>NZ</u>	<u>PHASE</u>	<u>IRIGID</u>
	0.0	0.0	0.0	0.0	0.0	0.0	0	0

***INITIAL_VELOCITY_RIGID_BODY (0)**

1	<u>PID</u>	<u>VX</u>	<u>VY</u>	<u>VZ</u>	<u>VXR</u>	<u>VYR</u>	<u>VZR</u>	<u>ICID</u>
		0.0	0.0	0.0	0.0	0.0	0.0	

***INITIAL_VELOCITY (0)**

1	<u>NSID</u>	<u>NSIDEX</u>	<u>BOXID</u>	<u>IRIGID</u>	<u>ICID</u>	
		0	0	0	0	
2	<u>VX</u>	<u>VY</u>	<u>VZ</u>	<u>VXR</u>	<u>VYR</u>	<u>VZR</u>
	0.0	0.0	0.0	0.0	0.0	0.0

Gravity

- *Load_Body_Z

Keyword Input Form

NewID Draw Pick Add Accept Delete Default Done

Use *Parameter Comment (Subsys: 1 Maccaferri_RMC_160_barrier_r6.k) Setting

LCID: Load curve ID *LOAD_BODY_Z (1)

1	LCID	SF	LCIDDR	XC	YC	ZC	CID
1	1	9.8000002	0	0.0	0.0	0.0	0

RMC160DF 6m/s 150m3

Keyword Input Form

NewID Draw RefBy Add Accept Delete Default Done 1 Gravity

Use *Parameter Comment (Subsys: 1 Maccaferri_RM PlotWindow-1

*DEFINE_CURVE_(TITLE) (3)

TITLE

Gravity

1	LCID	SIDR	SFA	SFO	OFFA	OFFO	DATTYP	LCINI
1	1	0	1.0000000	1.0000000	0.0	0.0	0	0

Repeated Data by Button and List

$\Delta 1$	O1
0.0	0.0

Data Pt. 1 Load XYData

1	0.0	0.0
2	0.1	1.0
3	100.0	1.0

Replace Insert Plot

Delete Help New

ChangeXY Copy Paste

COMMENT:

Total Card: 3 Smallest ID: 1 Largest ID: 3 Total deleted card: 0

PlotWindow-1

RMC160DF 6m/s 150m3

Define Curve

A Curve 1

SRS Title Scale Attr Filter Print Save Load Oper Hide Close Quit

Boundary conditions

- Movement
 - e.g. *Boundary_Prescribed_Motion_Set

*BOUNDARY_PRESCRIBED_MOTION_SET_(ID) (2)

ID	TITLE
1	DebrisinflowY-direction

1	NSID	DOF	VAD	LCID	SF	VID	DEATH	BIRTH
1	1	2	0	2	5.9000001	0	0.0	0.0

COMMENT:

DOF:=Applicable degrees-of-freedom:
EQ.1: x-translational DOF,
EQ.2: y-translational DOF,
EQ.3: z-translational DOF,

Displacement boundary conditions

- Constraints
 - e.g. *Boundary_SPC_Set

*BOUNDARY_SPC_SET_(ID) (2)

ID	TITLE	NSID	CID	DOFX	DOFY	DOFZ	DOFRX	DOFRY	DOFRZ
1		2	0	1	1	1	0	0	0

COMMENT:

Control parameters

Commonly used

- *Control_Termination
- *Control_Timestep
- *Control_Energy

Termination

- The time when to stop computation

Keyword Input Form

Use *Parameter Comment

Clear Accept Delete Default Done

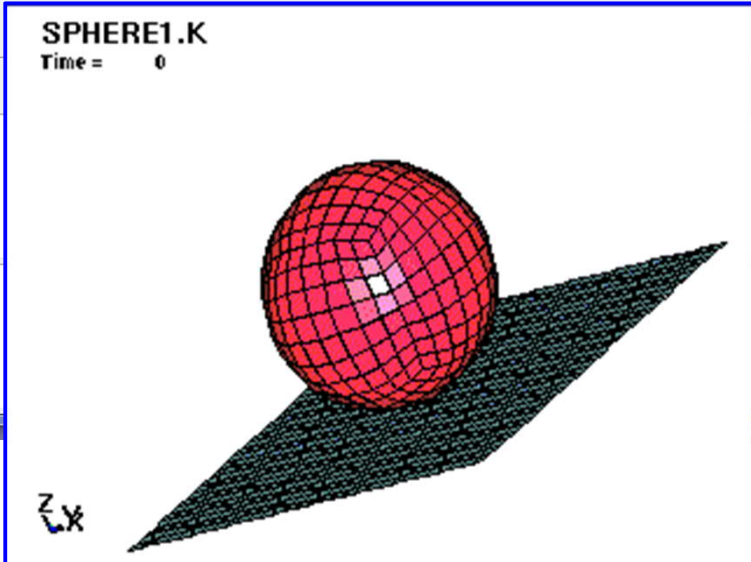
(Subsys: 1 sphere1.k) Setting

***CONTROL_TERMINATION (1)**

1	ENDTIM	ENDCYC	DTMIN	ENDENG	ENDMAS	NOSOL
	1.0000000	0	0.0	0.0	0.0	0

COMMENT:

SPHERE1.K
Time = 0

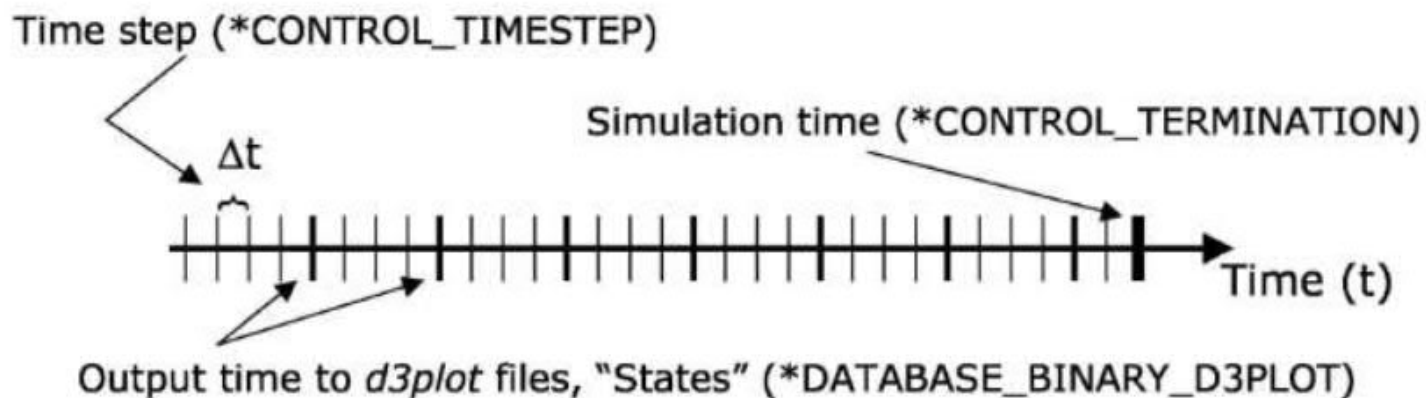


Material arrange

- CONTACT
- CPU
- DAMPING
- ENERGY
- OUTPUT
- SHELL
- TERMINATION**
- TIMESTEP
- DATABASE
- ELEMENT
- INITIAL
- KEYWORD
- MAT
- NODE
- PART
- SECTION
- TITLE

Timestep

- The time step to proceed explicit calculation
- Time step size depends on
 - Element size, element formulation
 - Material properties, e.g. modulus



$$C_{AcousticWaveSpeed} = \sqrt{\frac{E_{Material}}{\rho_{Material}}}$$

$$\Delta ExplicitTimestep = \frac{Length_{Element}}{C_{Wavespeed}}$$

$$\Delta Timestep_{CFL} = (0.9)\Delta ExplicitTimestep$$

Scale factor for computed time step

Keyword Input Form

Clear Accept Delete Default Done

Use *Parameter Comment

(Subsys: 1 sphere1.k) Setting

***CONTROL_TIMESTEP (1)**

1	<u>DTINIT</u>	TSSFAC	<u>ISDO</u>	<u>TSLIMIT</u>	<u>DT2MS</u>	<u>LCTM</u> <input type="checkbox"/>	<u>ERODE</u>	<u>MS1ST</u>
	0.0	0.9	0	0.0	0.0	0	0	0
2	<u>DT2MSE</u>	<u>DT2MSLC</u> <input type="checkbox"/>	<u>IMSC</u> <input type="checkbox"/>	<u>UNUSED</u>	<u>UNUSED</u>	<u>RMSCL</u>		
	0.0	0	0	0	0	0.0		

COMMENT:

TSSFAC:=Scale factor for computed time step. (Default =0.9. If high explosives are used, the default is lowered to 0.67).

Tips: if ALE involved, have the time step scale factor reduced from the default of 0.9 to **somewhere around 0.6** in order to maintain a stable solution

Energy

Keyword Input Form

Energy related to rigid part

Use *Parameter Comment

Clear Accept Delete Default Done

(Subsys: 1 sphere1.k) Setting

*CONTROL_ENERGY (1)

1 HGEN RWEN SLNTEN RYLEN

1 2 1 1

Energy related to sliding contact

Related to damping energy

COMMENT:

HGEN:=Hourglass energy calculation option.
EQ.1: hourglass energy is not computed (default),
EQ.2: hourglass energy is computed and included in the energy balance.

Remark on Energy in LS-DYNA

$$\underbrace{E_{kin} + E_{int} + E_{si} + E_{rw} + E_{damp} + E_{hg}}_{\text{total energy } E_{total}} = E_{kin}^0 + E_{int}^0 + W_{ext}$$

E_{kin} = current kinetic energy

E_{int} = current internal energy

E_{si} = current sliding interface energy (including friction)

E_{rw} = current rigid wall energy

E_{damp} = current damping energy

E_{hg} = current hourglass energy

E_{kin}^0 = initial kinetic energy

E_{int}^0 = initial internal energy

W_{ext} = external work

Potential energy is NOT included in this energy balance equation!!

Unit system – keep consistent

Mass	Length	Time	Force	Stress	Energy
kg	m	s	N	Pa	N·m (J)
g	mm	ms	N	MPa	N·mm
kg	mm	s	mN	kPa	mN·mm
...

Post-processing guidelines

Before running a model

The image shows a 3D finite element model of a structure, likely a ship's hull or a similar component, with a yellow mesh on top and a red mesh on the bottom. The model is titled "RMC160DF_6m/s_150m3". On the left, a tree view lists the assembly components:

- Assembly 1
 - FEM Parts
 - 1 Topo_bottom
 - 2 Topo_side
 - 3 Container
 - 4 Debris
 - 5 Horizontal cable
 - 6 Brake element
 - 7 Side cable
 - 8 Ring 1
 - 9 Ring 2
 - 10 Shackles
 - 11 Null membrane
 - Keyword Entity
 - Boundary
 - Contact
 - Define
 - Load
 - Set

On the right, the Keyword Manager window is open, showing a list of keywords and their counts. The "DATABASE" keyword is highlighted in yellow. A red dashed box encloses the following keywords: CONTROL, DATABASE, ASCII_option, BINARY_D3PLOT, and EXTENT_BINARY.

Name	Count
ALE	2
BOUNDARY	4
CHANGE	3
CONSTRAINED	3
CONTACT	1
CONTROL	1
DATABASE	3
ASCII_option	1
BINARY_D3PLOT	1
EXTENT_BINARY	1
DEFINE	3
ELEMENT	95603
HOURGLASS	1
KEYWORD	1
LOAD	1
MAT	8
NODE	111960
PART	11
SECTION	9
SET	5
TITLE	1

At the bottom of the Keyword Manager window, there are several buttons: "Model Check", "Keyword Del", "ResForm", "ExpandAll", and "CollapseAll".

Keywords defining what data to output

Keyword	Output option	Remark
*Database_Binary_D3plot	Set DT	DT, time interval to output d3plot file used for animation, e.g. DT=0.1
*Database_ASCII_Option	GLSTAT, MATSUM,RCFORC SLEOUT, SPCFORC, NCFORC	Minimum recommended set, in ASCII format
*Database_Extent_Binary	IEVER=1, STSSZ=3	Output individual d3plot file at every time interval to avoid result file too large
*Database_Binary_Intfor	Set DT	Contact forces and stresses that can be used for fringe plotting

Keyword Input Form

Use *Parameter Comment (Subsys: 1 Maccaferri_RMC_160_barrier_r6.k) Setting

*DATABASE_BINARY_D3PLOT (1)

ID	Keyword	Value	Option	Value	Option	Value	Option	Value
1	DT	0.1000000	LCDI	0	BEAM	0	NPLTC	0
2	IOOPT	0						

COMMENT:

Total Card: 1 Smallest ID: 2 Largest ID: 2 Total deleted card: 0

- CONstrained 3
- CONTACT 1
- CONTROL 2
- DATAbase 3
 - ASCII_option 1
 - BINARY_D3PLOT 1
 - EXTENT_BINARY 1
- DEFINE 3
- ELEMENT 95603
- HOURLASS 1
- KEYWORD 1
- LOAD 1
- MAT 8
- NODE 111960
- PART 11
- SECTION 9
- SET 5
- TITLE 1

Output files useful in post-processing ALE simulation

Keyword	Output option	Remark
*Database_FSI		A file named as dbfsi in ASCII format, reports time history of coupling forces as well as coupling pressure
*Database_Binary_FSIFOR#	Set DT	A binary database can be read into LS-PrePost to enable fringe plots of coupling pressure and forces

Certain procedures should be followed when using this keyword, refer to User Manual (Vol I)

Concluding remarks

Modelling check list - 1

➤ Mesh considerations

- Does the mesh size give a reasonable time step?
- Are reasonable aspect ratios for solids and shells being used
- If using under-integrated elements, is hourglass energy small enough or the level of hourglassing acceptable?
- Are duplicate elements / nodes avoided?

➤ Hourglass

- Are ALE fluids, which require lowering the hourglass coefficients, being used?

➤ Material models

- Are strain-rate effects important?
- Has a reasonable range for the material input curves been defined, so that rediscrretization won't affect the resolution in the area of interest?

Modelling check list - 2

➤ Contacts

- Have checks for redundant contacts been completed?
- Have checks for significant penetration between contacting parts been completed?

➤ General quality check

- Is the time-step small enough given the relative velocity of the impact, and, if not, has reducing the time step scaling factor been considered?
- Is the time-step unreasonably unstable and small that a revisit to time step control parameters needed

➤ Output data

- Are anticipated results (node force, axial force etc.) that would be useful for interpretation all defined in the *Database keyword and relevant cards?

➤ Finally, for all categories

- **As a beginner, if not sure, use default setting**

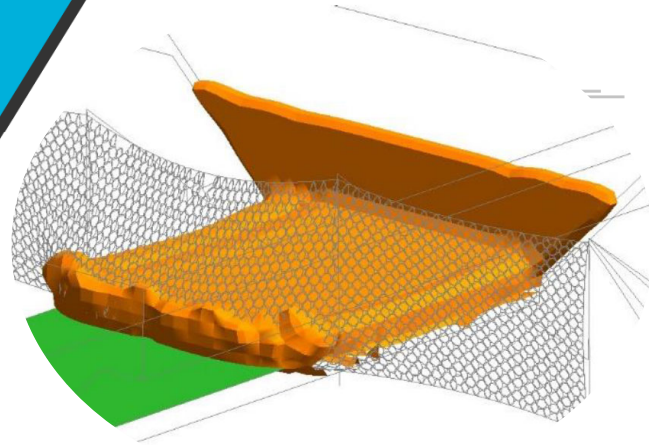
Useful references

- <https://www.dynasupport.com/manuals>
 - LS-DYNA User Manual (Vol I to III, latest version)
 - LS-DYNA Theory Manual (2017 Draft version)
- <https://www.dynasupport.com/tutorial>
- LS-DYNA Aerospace Working Group
<https://awg.lstc.com/tiki-index.php?page=Resources>

Thank you.

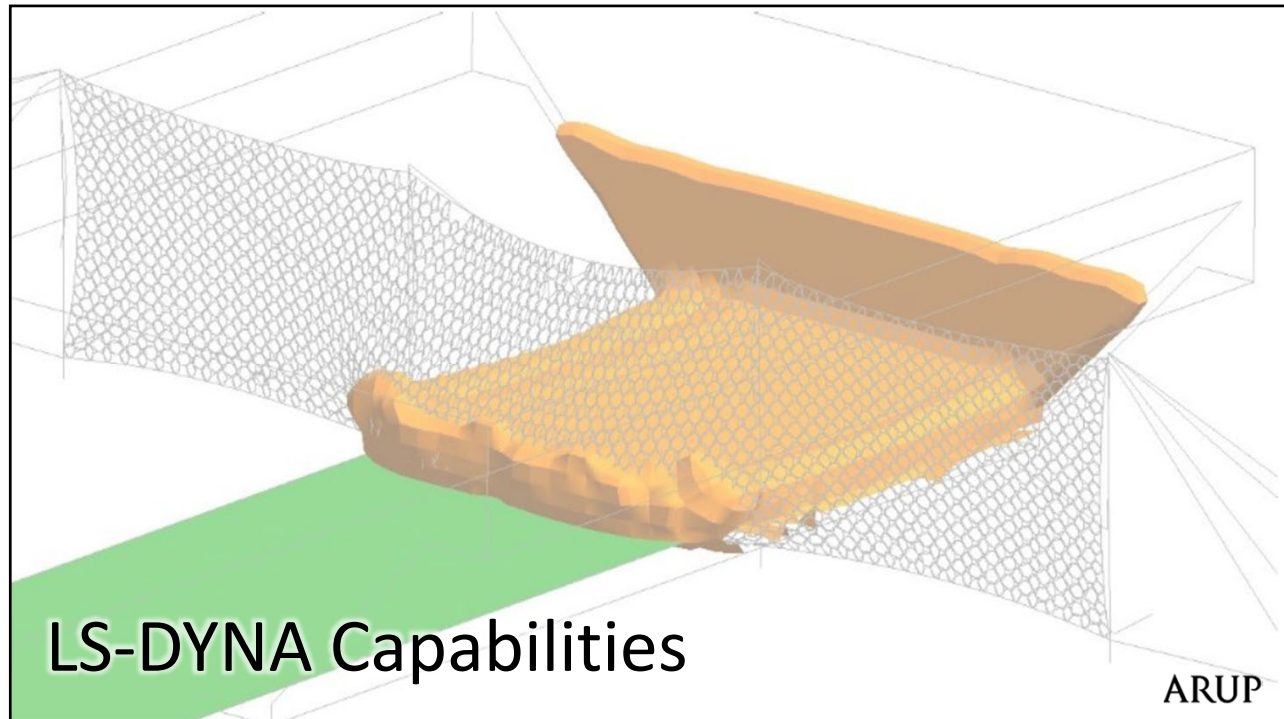
Design Experience Sharing and Demonstration of Using LS-DYNA

Jack Yiu and Arthur Cheung
Ove Arup & Partners Hong Kong Limited
16 April 2019



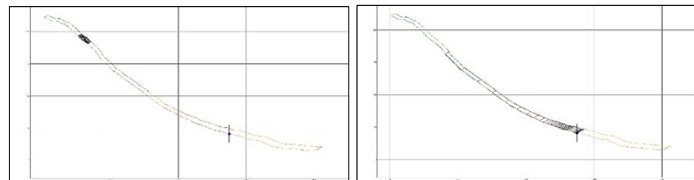
Outline

- LS-DYNA Capabilities
- Debris Mobility Modelling
 - Model Setup Illustration
 - Design Case Sharing – Fo Tan
- Structural Analysis of Flexible Barrier
- Couple Analysis with Barrier
 - Design Case Sharing – Flexible Barrier Performance Optimisation

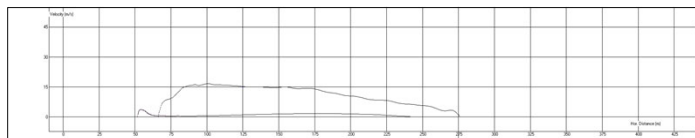


Current Approach of Flexible Barrier Design

- Debris mobility prediction using simplified 2D analysis e.g. DAN/W
- Debris runout path is pre-defined and much idealised
- Debris volume and maximum frontal velocity at a particular check point for flexible barrier design



Debris run-out prediction using DAN/W (from source to downslope)



Velocity of the debris respect to horizontal run-out distance

- Two approaches for the barrier design:
 - Energy approach: select a rockfall barrier with energy rating that match the predicted maximum kinetic energy
 - Force approach: pseudo-static force to explicitly design the barrier

Explore the Possibility of Using Advanced Numerical Tools

- Shortcoming of the existing approaches:
 - Energy approach: energy rating of barrier was based on rock fall tests, not debris flow
 - Force approach: interaction of debris and barrier not considered, hence the flexible barrier design will be too conservative and onerous.
- Arup works with the GEO to investigate the use of advanced numerical methods to study the interaction of debris flow and flexible barrier → LS-DYNA, a multi-purpose finite element program for linear and non-linear mechanics, large deformation
- The objective of the previous works:
 - Provide better prediction of debris mobility for flexible barrier design
 - Improve the accuracy and cost-effectiveness of flexible barrier design
 - Provide insight for the development of standardised and rationalised design method

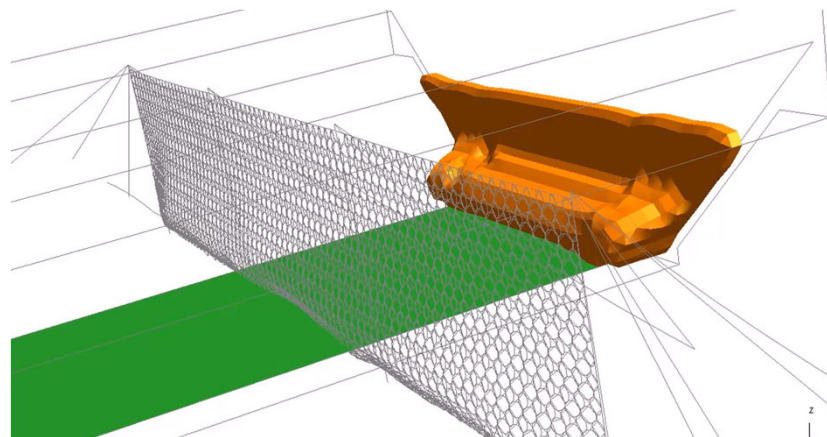
LS-DYNA Capabilities



Advanced numerical
package used –
LS-DYNA



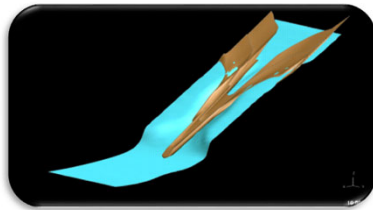
- LS-DYNA is a multi-purpose finite element program for linear and non-linear mechanics



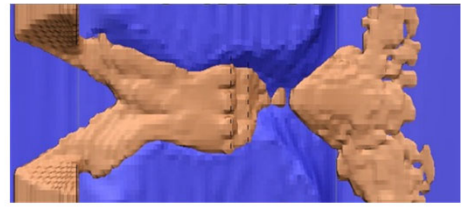
ARUP

Why LS-DYNA?

- Track records on impact analyses
- Able to model large deformation and movement of debris mass with the use of advanced finite element meshing method
- Able to simulate coupled soil-structure interaction
- Flexible to make changes to codes for different applications



Conventional meshing method in Finite Element analysis fails to capture large soil deformation

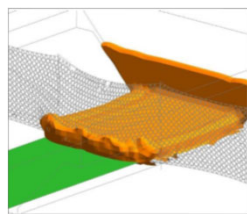


LS-DYNA ALE meshing technique allows the simulation of soil structure interaction between baffles and landslide debris

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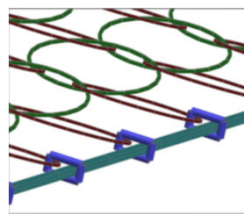
Development since 2012

2012 - 2014



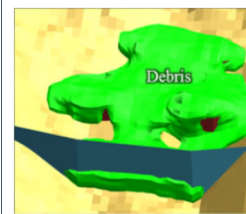
The **Interactions** between Landslide Debris and Flexible Barriers

2014 - 2016



Energy Balance of Flexible Barrier System

2016 - current



Engineering Application Perspective

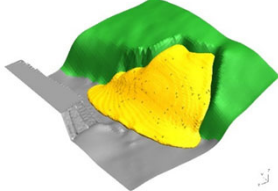
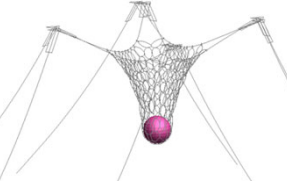
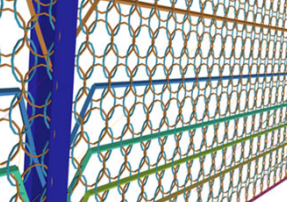
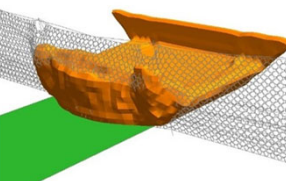
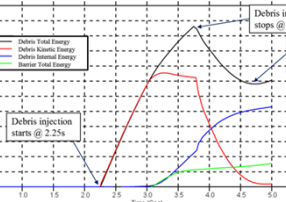
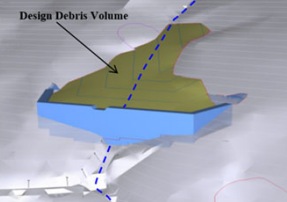
Research

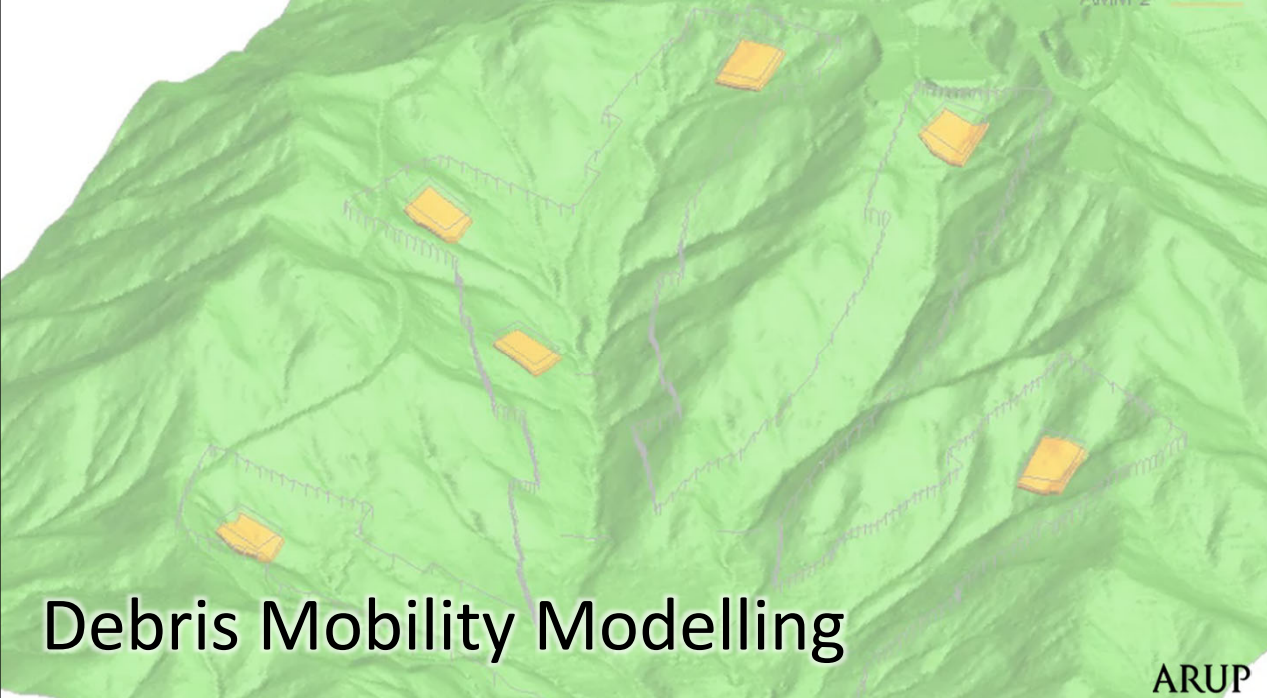
Validation

Adopt in Real Work

LS-DYNA Capabilities

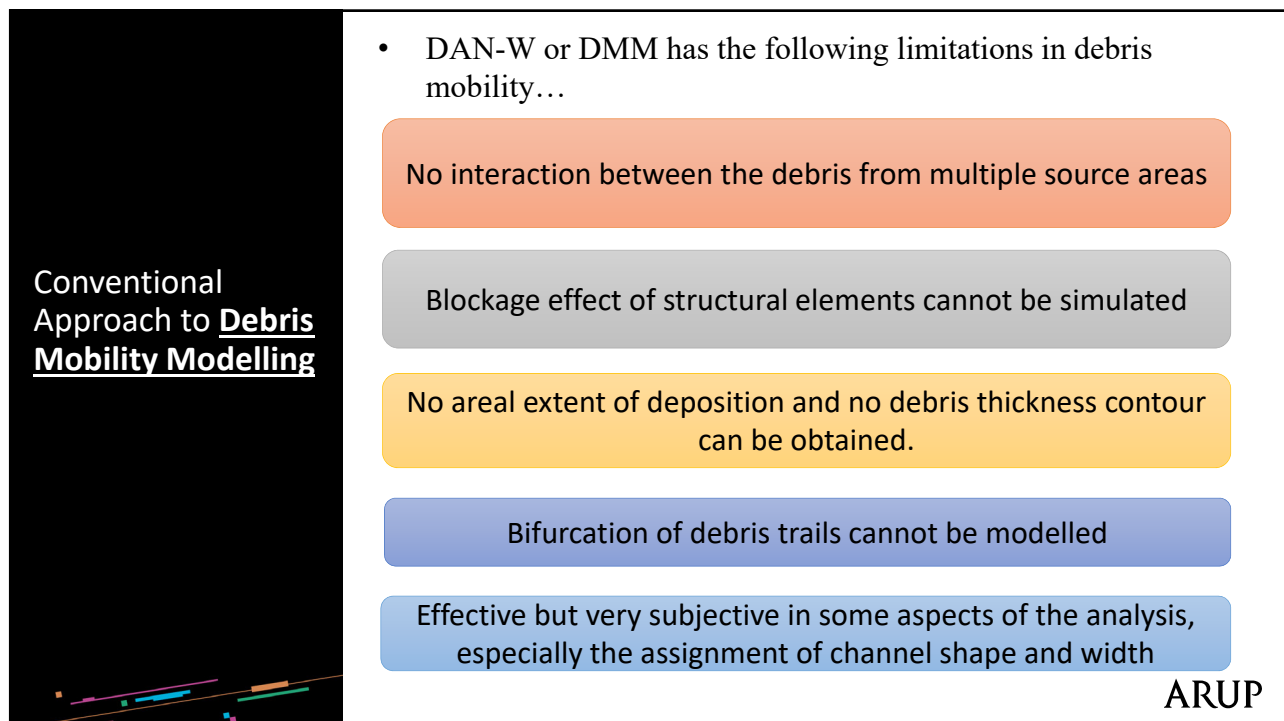
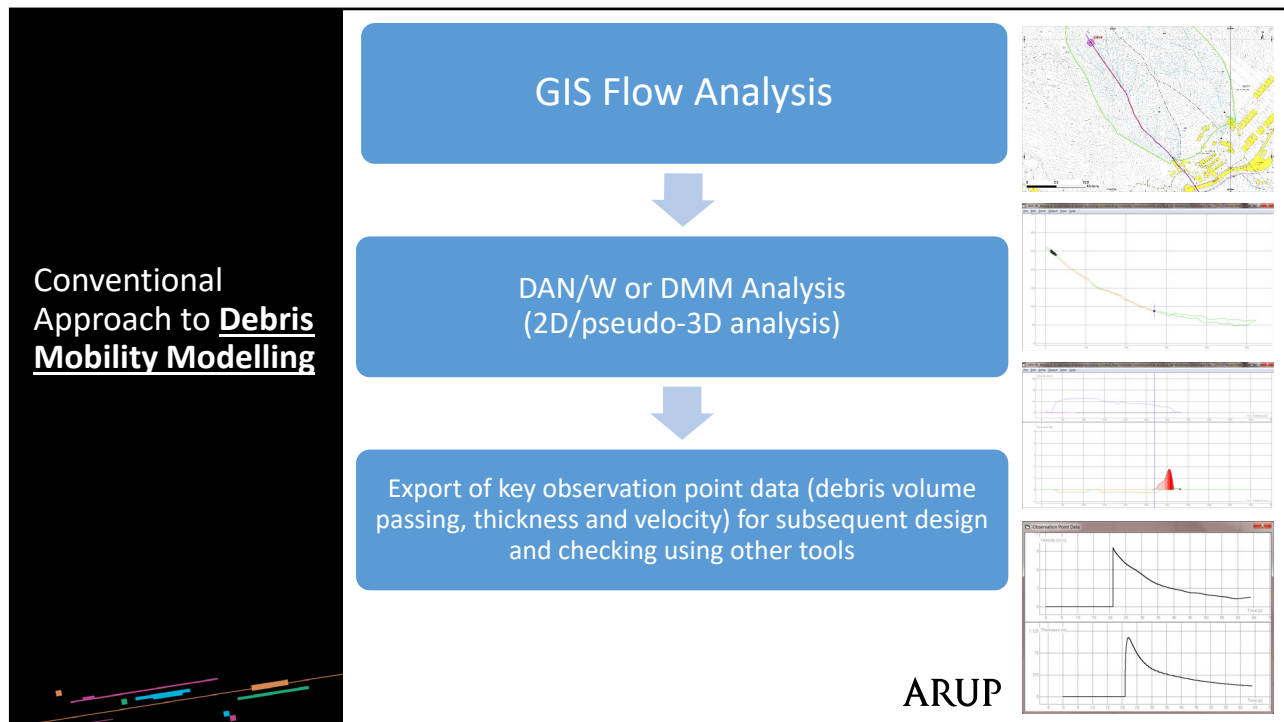
ARUP

	<p>Debris Mobility Modelling</p> <p>1</p>		<p>Rock Fall</p> <p>2</p>
<p>LS-DYNA Capabilities</p>		<p>Interaction between the flexible barrier and the landslide debris</p> <p>3</p>	
 <p>ALC Barrier 230cu m - Energy vs. Time</p> <p>Debris injection starts @ 2.25s</p> <p>Debris injection stops @ 3.8s</p>	<p>Energy Balance</p> <p>4</p>	 <p>Design Debris Volume</p>	<p>Optimisation in Design of Flexible and Rigid Barriers</p> <p>5</p> <p>ARUP</p>



Debris Mobility Modelling

ARUP



Conventional Approach to Design of Structural Countermeasures

1

- Debris mobility modelling carried out separately.

2

- Structural analyses of barriers carried out separately.

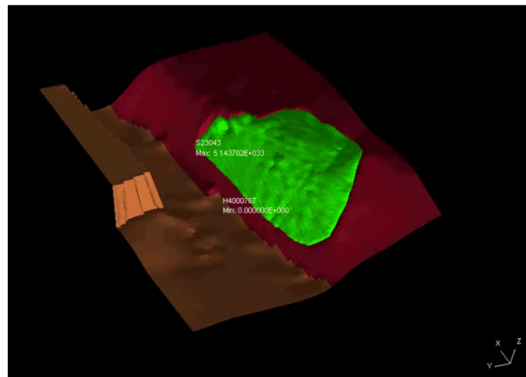
Problem

- Could not realistically account for the dynamic debris-barrier interaction

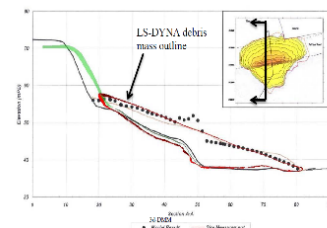
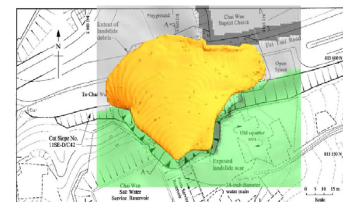
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Open Hillslope Landslide (OHL)

- Pure frictional rheology model adopted in the LS-DYNA simulation was proven to be successful in predicting debris slide. Example of Fei Tsui Road Landslide occurred in Hong Kong in Year 1995



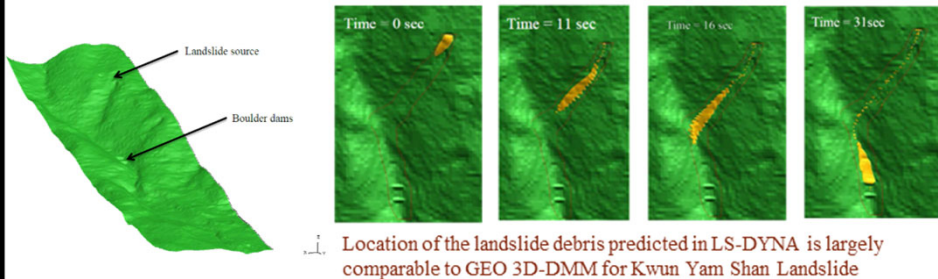
Fei Tsui Road Landslide LS-DYNA Animation



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Channelised Debris Flow (CDF)

- Introduction of Voellmy rheology by modifying the program codes to suit typical debris flow hazards in Hong Kong.
- Example of Kwun Yam Shan Landslide occurred in Hong Kong in 2005



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Make changes to program codes

- Tailor made to make changes to codes for different applications according to client's needs

Additional Voellmy resistance term at the ALE solid / rigid shell interface

$$T = A_i \left[\gamma H_i \left(\cos \alpha + \frac{a_c}{g} \right) \tan \phi + \gamma \frac{v_i^2}{\xi} \right]$$

In the interaction input for ALE solid –

“*CONSTRAINED_LAGRANGE_IN_SOLID”

an extra “damping” term is added to for (γ / ξ) which applies an resistance to the interface based on v^2

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Calibration of Landslides in Hong Kong and overseas

- Debris mobility modelling using LS-DYNA have been calibrated against several well-documented landslide in Hong Kong and overseas to ensure program appropriateness and robustness in debris mobility modelling

- Yu Tung Road landslide on 7th June 2008
- Kwun Yam Shan landslide on 22nd August 2005
- Sham Tseng San Tsuen debris flow on 23rd August 1999
- Fei Tsui Road landslide on 13th August 1995

HONG KONG

- USGS laboratory flume tests reported by Iverson et al. (2004)
- Rock fall tests by Volkwein (2004)
- Illgraben flexible barrier field tests

OVERSEAS

- Pre-approved 3D numerical software for debris mobility by GEO in March 2016

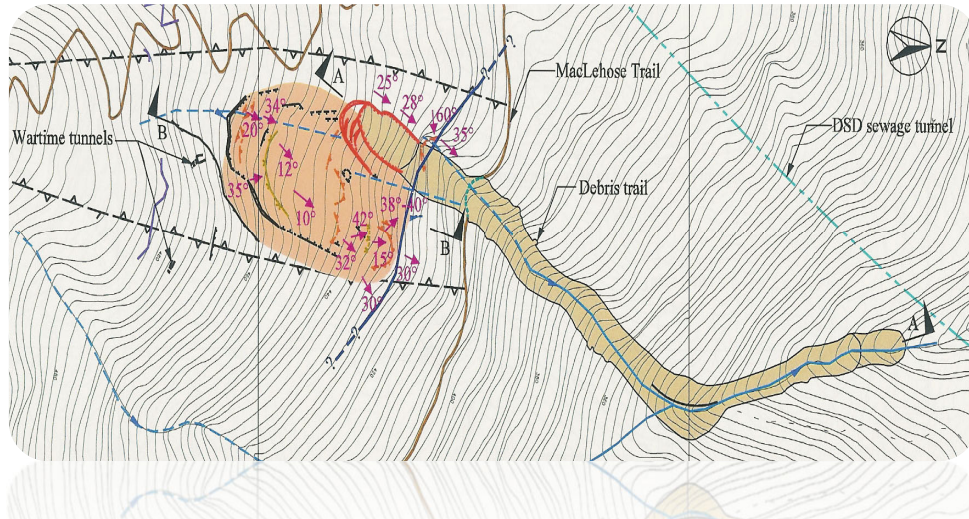
ARUP

Model Setup Illustration

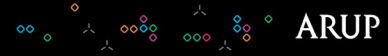
From Recent JTC1 Benchmarking Exercise

ARUP

A historical landslide catchment in Hong Kong

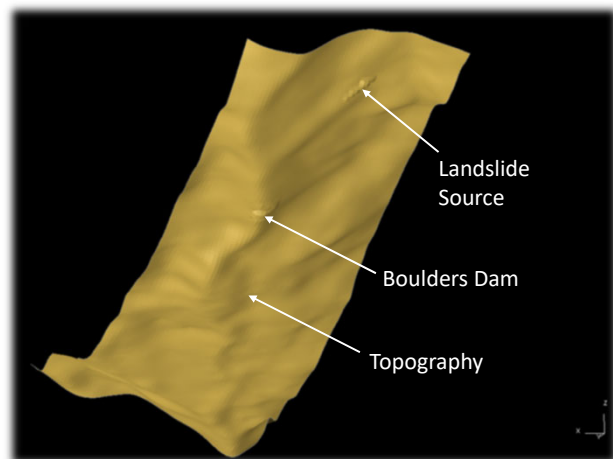
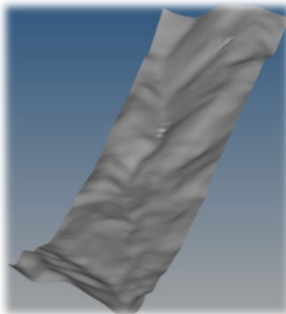


Model Setup Illustration



Model Setup – The Topography

- Modelled by rigid shell elements
- Resolution = 5m x 5m
- No. of elements = 11,550

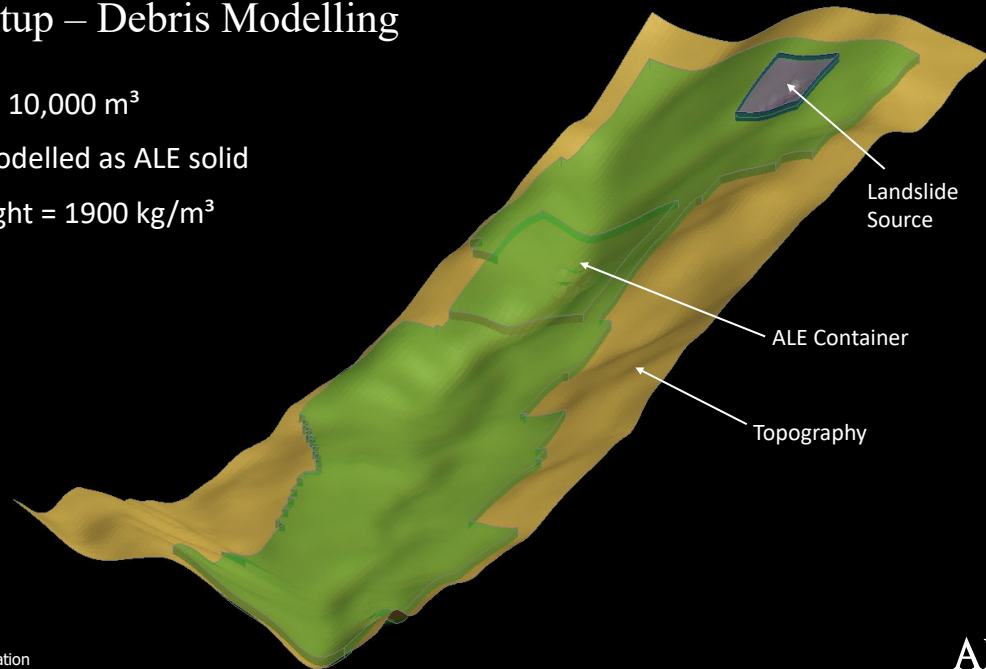


Model Setup Illustration



Model Setup – Debris Modelling

- Volume = 10,000 m³
- Debris modelled as ALE solid
- Unit Weight = 1900 kg/m³

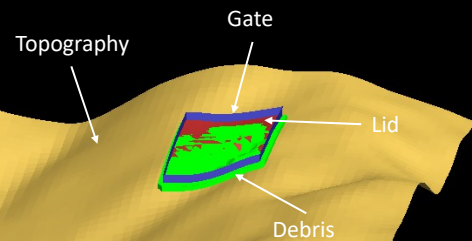


Model Setup Illustration

ARUP

Model Setup – Gravity Initialisation

- Debris mass initialised at source location by applying gravity load within first 2 seconds
- An artificial rigid tube and lid, acting as the gate, to confine and restrict the debris mass movement during initialization
- The gate has very low contact friction with the debris mass to minimize disturbance

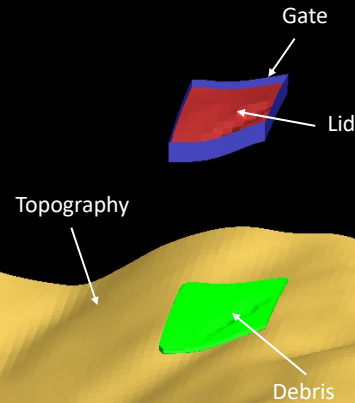


Model Setup Illustration

ARUP

Model Setup – Gravity Initialisation

- Debris mass initialised at source location by applying gravity load within first 2 seconds
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Model Setup Illustration

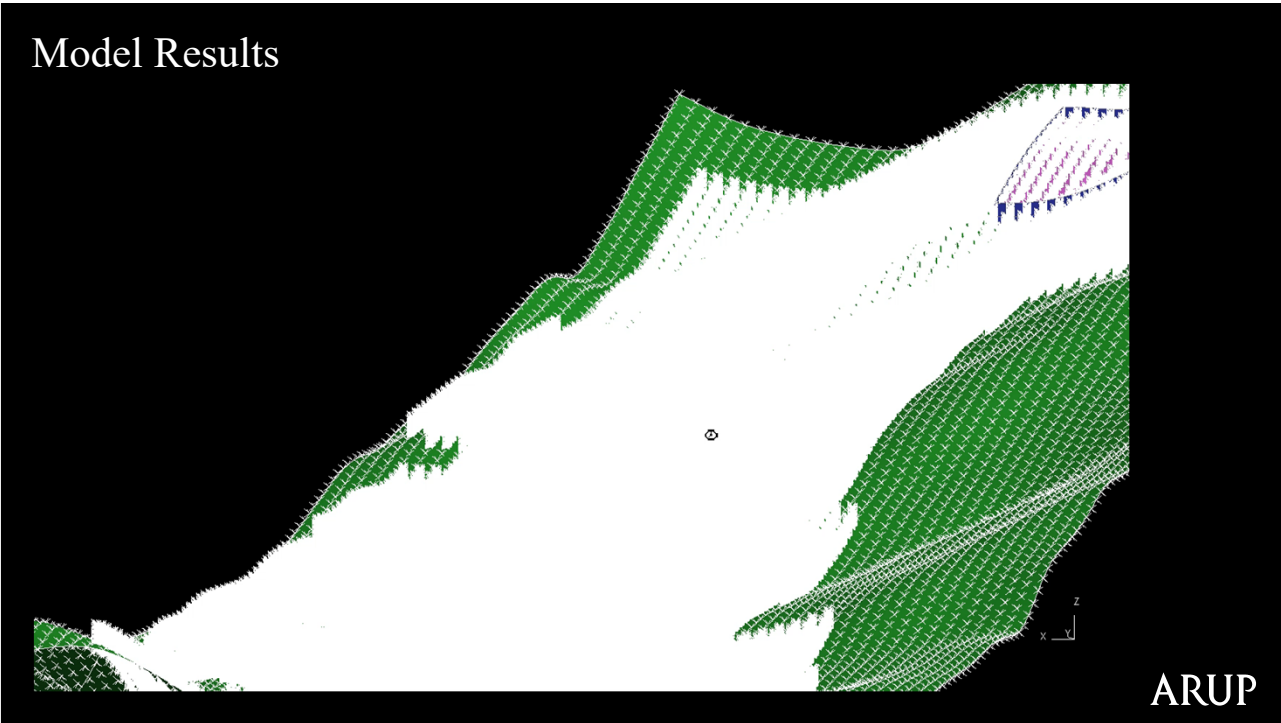
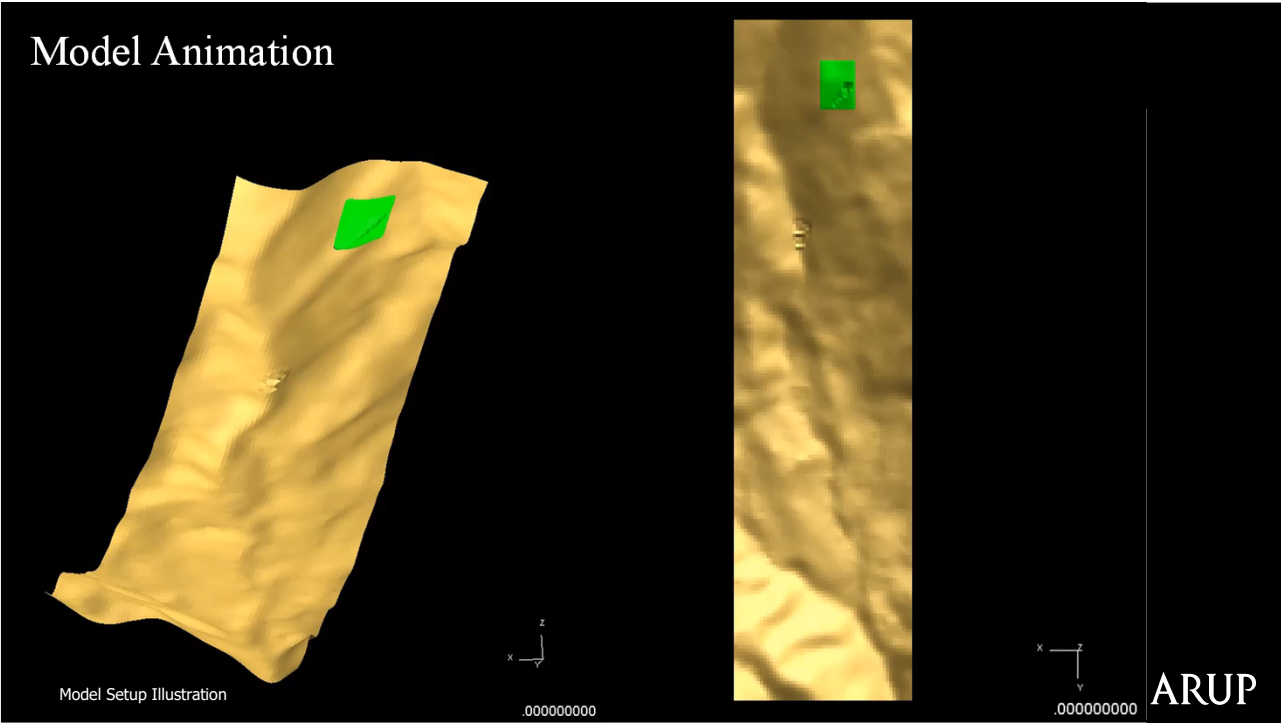
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Setup – Debris Mass and Basal Friction

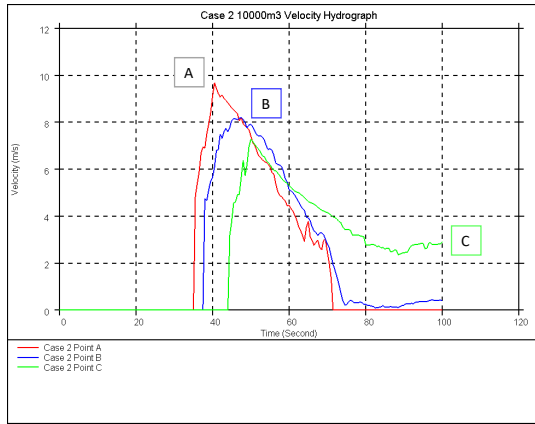
- Debris mass movement captured at regular 0.5s interval

Rheology	Material Property	Adopted input parameter s	Remarks
Voellmy	Internal friction angle, φ_i	15°	Arup (2014)
	Basal friction angle, φ_b	8°	GEO TGN 29 (Adverse Site Setting Parameters)
	Turbulence coefficient	500 m/s ²	

Model Setup Illustration

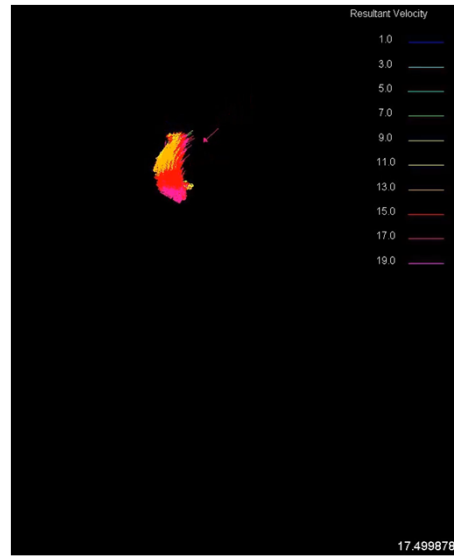


Model Results – Velocity Hydrograph

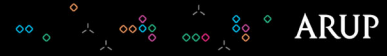


	Point A	Point B	Point C
Maximum Velocity (m/s)	9.7	8.2	7.3
Time Recorded (s)*	40.5	47.5	50.0

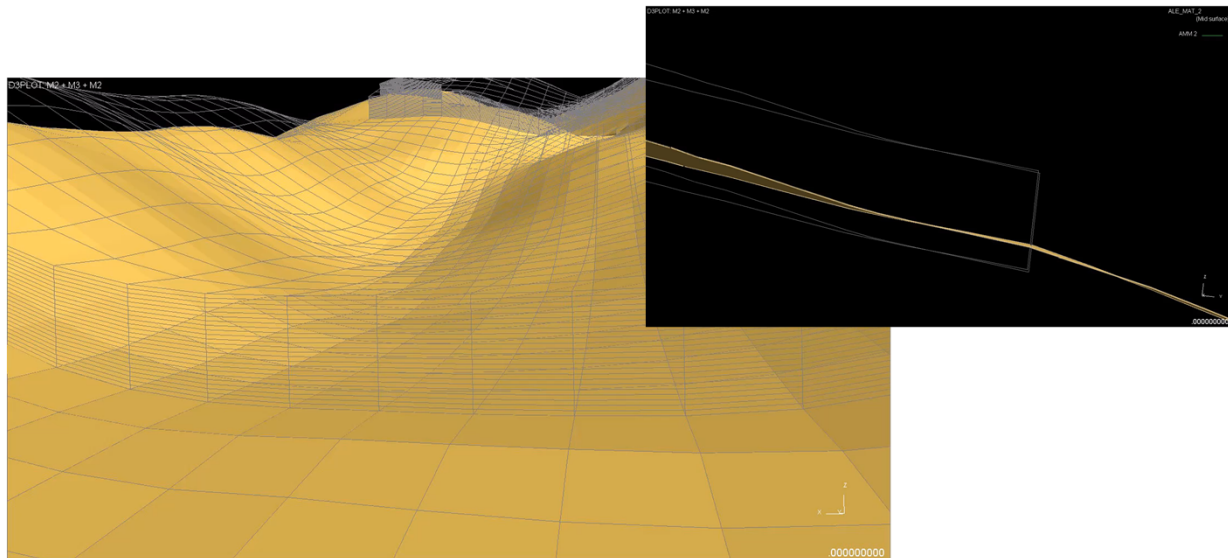
*Debris are allowed to slide downslope at t=2s



Model Setup Illustration



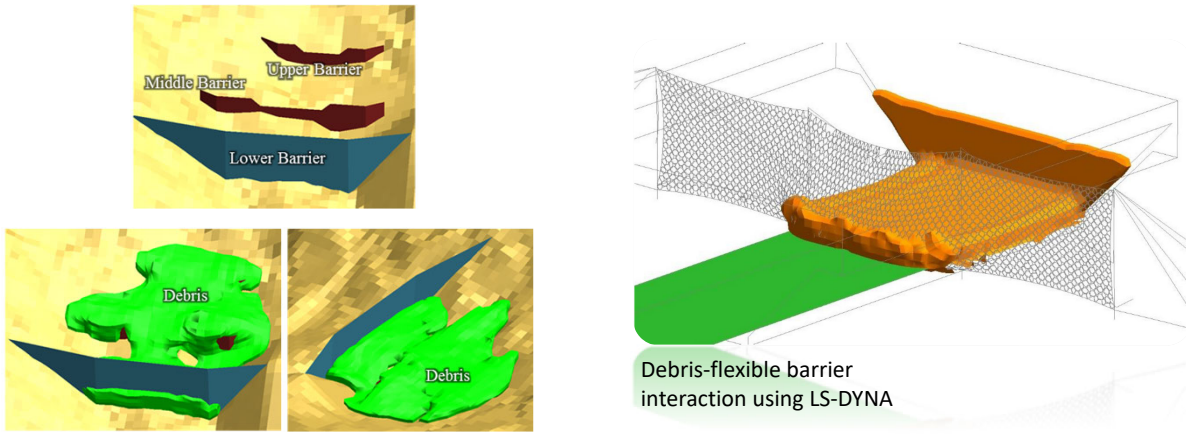
Model Animation – Debris Thickness at Point A



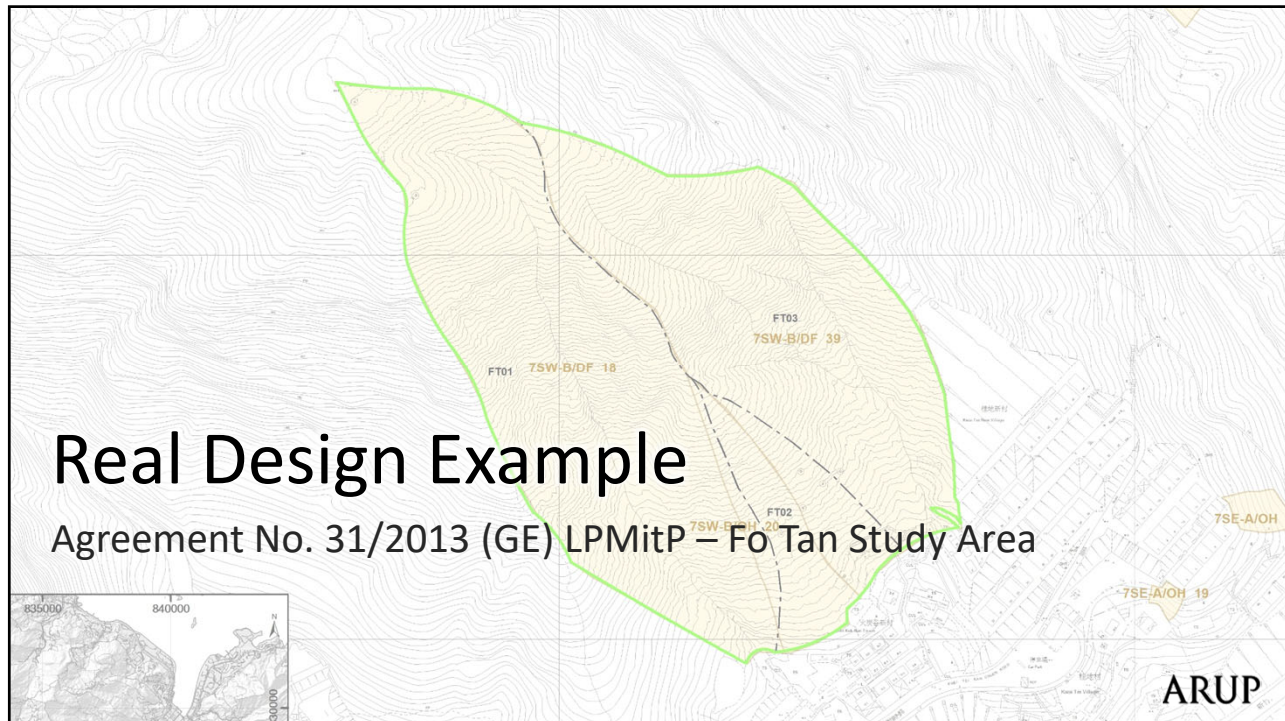
Model Setup Illustration



Possible Mitigation Measures



Model Setup Illustration



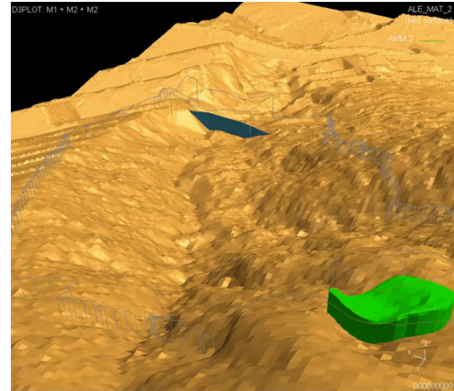
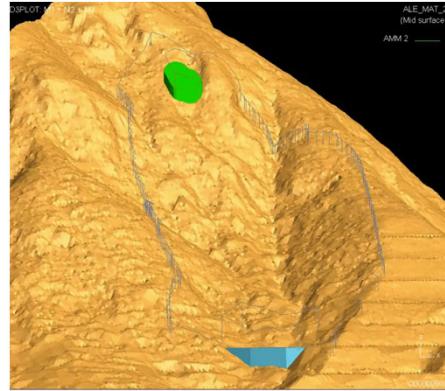
Real Design Example

Agreement No. 31/2013 (GE) LPMitP – Fo Tan Study Area

Agreement No.
31/2013 (GE)
LPMitP –
Fo Tan Study Area

Fo Tan Design Option 1

- A 5.0m high rigid barrier
- 2 rows of baffles
- Maintenance stairways



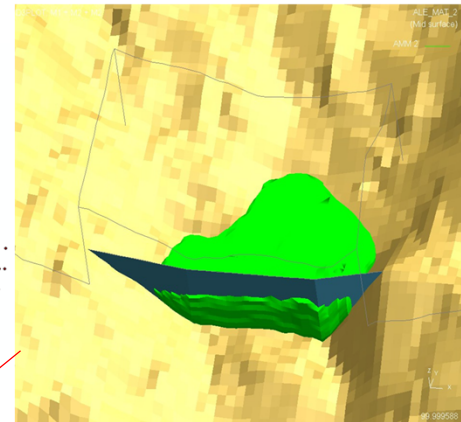
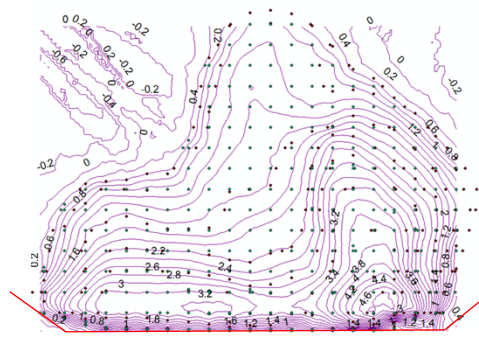
Catchment No. FT03

ARUP

Agreement No.
31/2013 (GE)
LPMitP –
Fo Tan Study Area

Fo Tan Design Option 1

Debris Thickness Contour (max. 4.6 m)

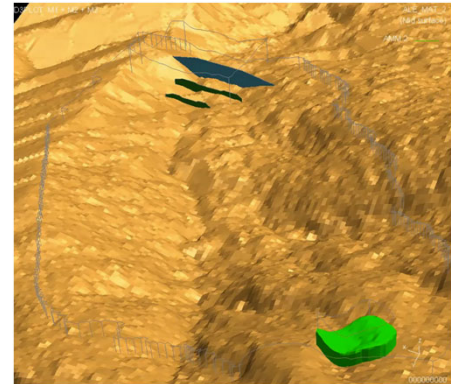
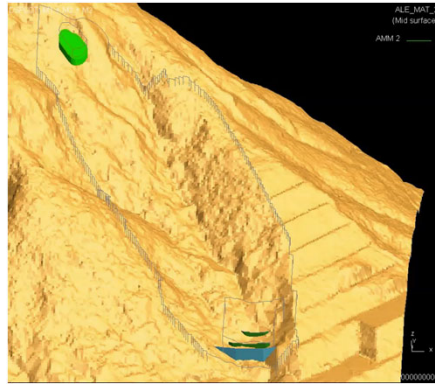


ARUP

Agreement No.
31/2013 (GE)
LPMitP –
Fo Tan Study Area

Fo Tan Design Option 2

- Two 2.5m high intermediate rigid barriers
- A 2.5m high terminal rigid barrier
- Baffles behind each barrier
- Maintenance stairways

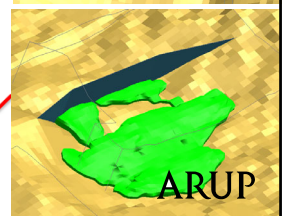
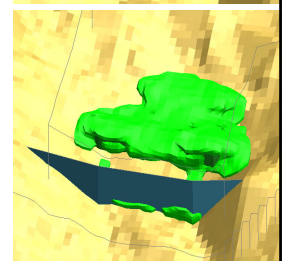
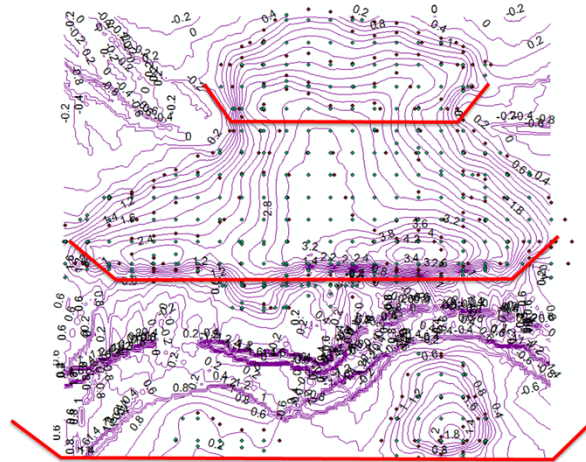


ARUP

Agreement No.
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LPMitP –
Fo Tan Study Area

Fo Tan Design Option 2

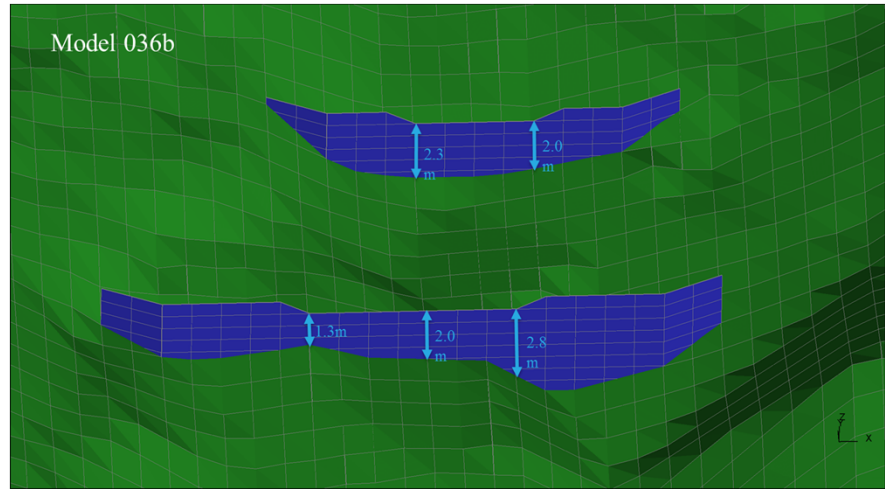
Debris Thickness Contour (max. 2.0m at the terminal barrier)



ARUP

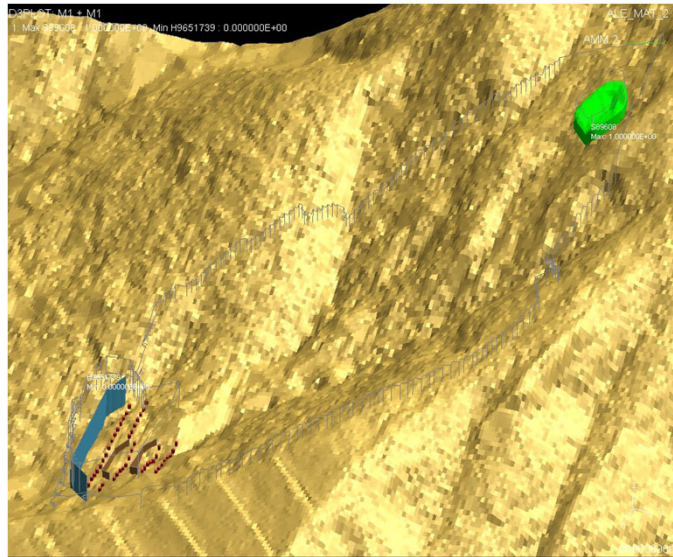
Agreement No.
31/2013 (GE)
LPMitP –
Fo Tan Study Area

Optimisation of rigid barrier design in terms of dimension and configuration based on topography from LiDAR data



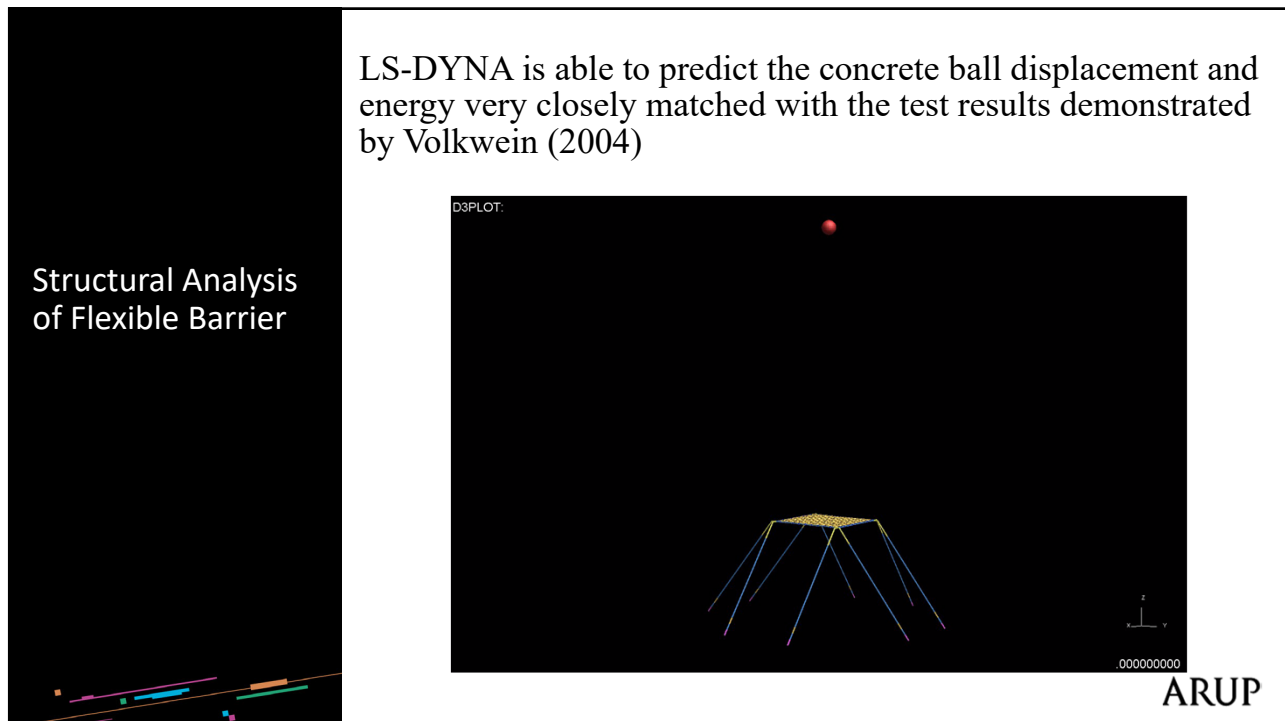
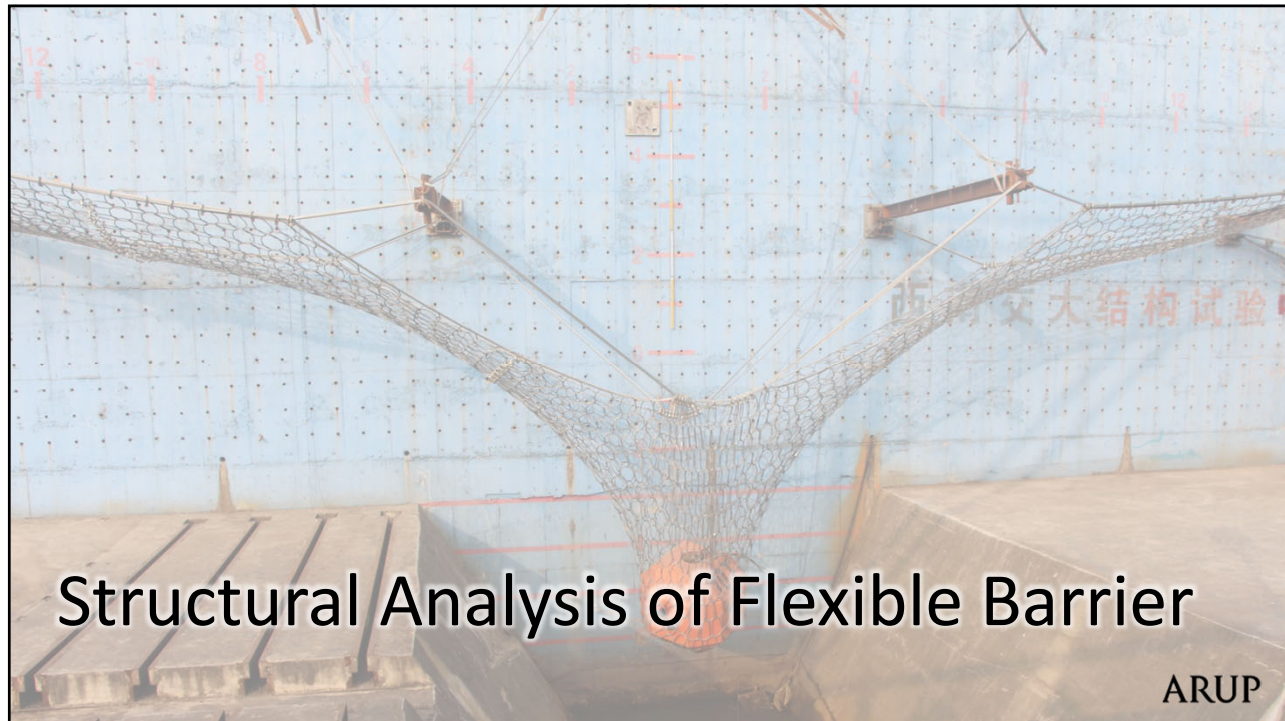
ARUP

Multiple Barriers with Baffles



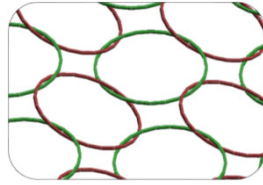
Design Demonstration – Fo Tan

ARUP



Structural Analysis of Flexible Barrier

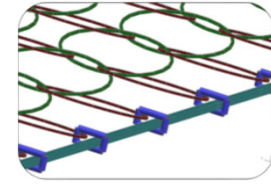
All structural components including the cable, shackles, brake rings and ring net were modelled using beam elements.



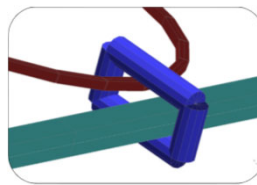
Ring Net



Connection



Cable

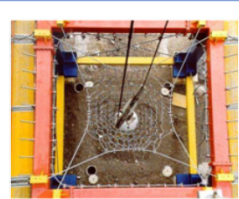


Shackles

ARUP

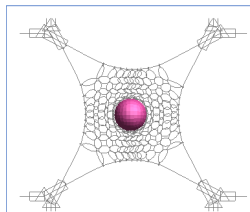
Structural Analysis of Flexible Barrier

Deformation matched.



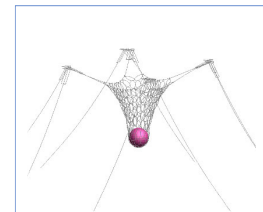
REAL TEST

Plan view of final position of
the concrete ball



LS-DYNA Simulation

Plan view of final position of
the concrete ball



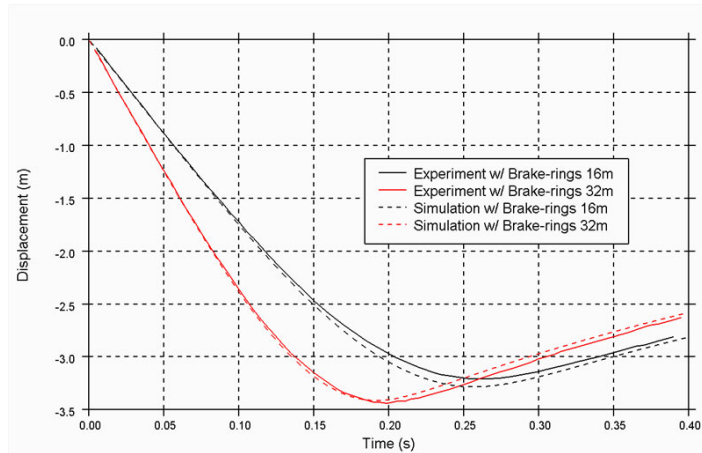
LS-DYNA Simulation

Deformation of the flexible
barrier in LS-DYNA

ARUP

Structural Analysis of Flexible Barrier

Results and comparison with the test results on vertical position of the concrete ball and tension force developed on the steel cables

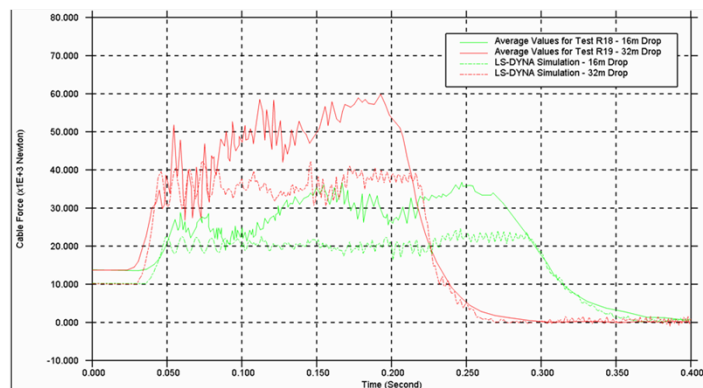


Displacement-time curves for LS-DYNA simulation and experimental results from Volkwein.



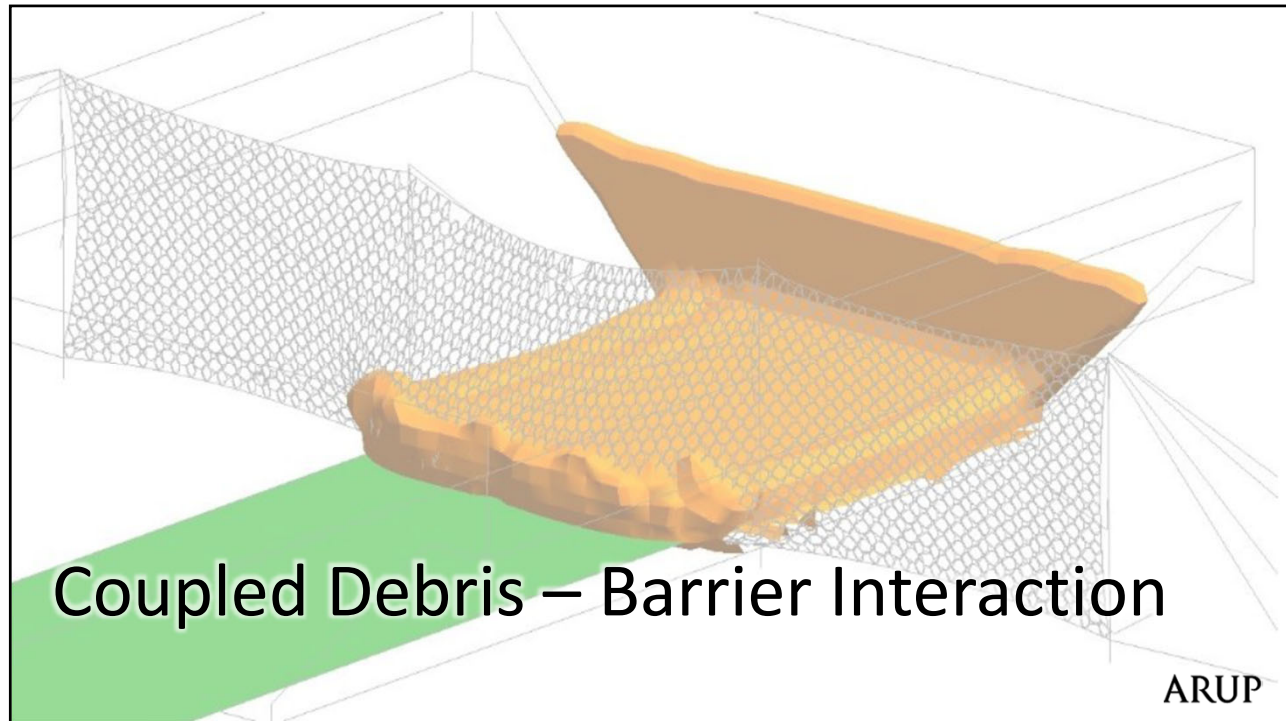
Structural Analysis of Flexible Barrier

Results and comparison with the test results on vertical position of the concrete ball and tension force developed on the steel cables



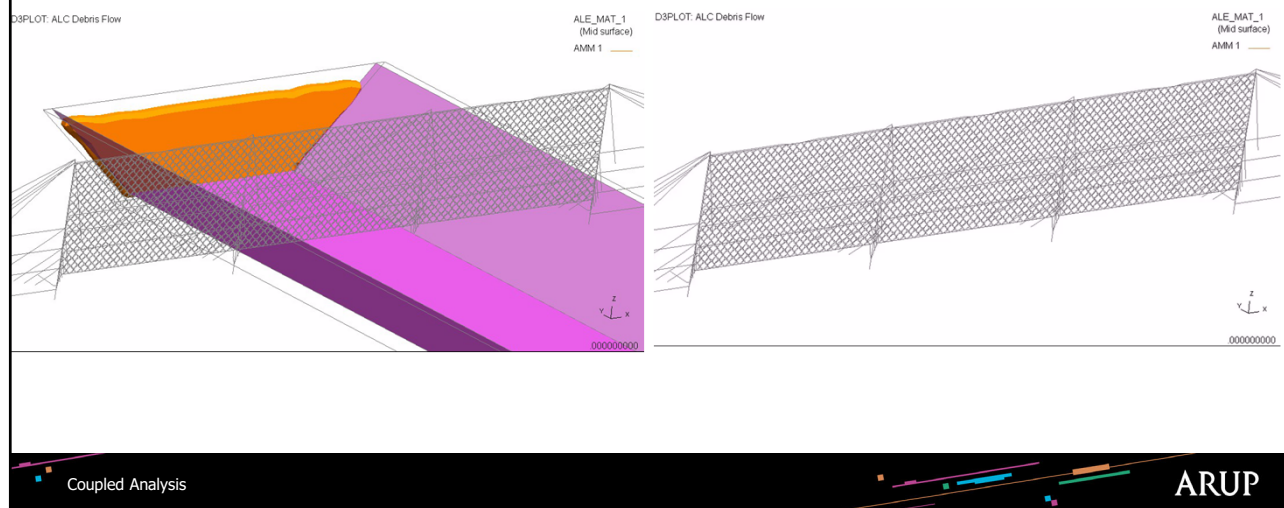
Cable force vs. time curves for LS-DYNA simulation and experimental results from Volkwein





Soil-Flexible Barrier Interaction

- With same modelling technique, the interaction between the debris flow and flexible barrier can be analysed. Force, velocity, energy vs time can be obtained.



Validation

- Coupled analysis between the Rockfall/Debris and Debris Retaining/Resisting Structures using LS-DYNA have been validated against several well-documented landslides in Hong Kong and overseas to ensure program appropriateness and robustness.

- Flexible Barrier Field Test in Illgraben, Switzerland
- Shallow Landslide Full-scale Field Test on Flexible Barrier in Veltheim, Switzerland
- Ship Impact Assessment on Pile Structural Foundations for Viaducts / Bridges
- HKUST Centrifuge Modelling of Debris Impact on Barriers

Validation Cases

- Use of LS-DYNA for the application of coupled analysis of interaction between rock/boulder/debris and debris-resisting barrier structures is approved by BD and can be used in all private / public works in 2018

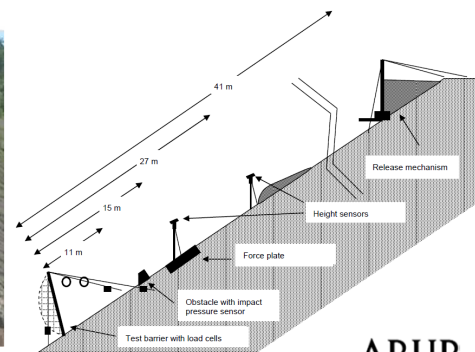
Coupled Analysis

ARUP

The Veltheim Field Test Model

Background

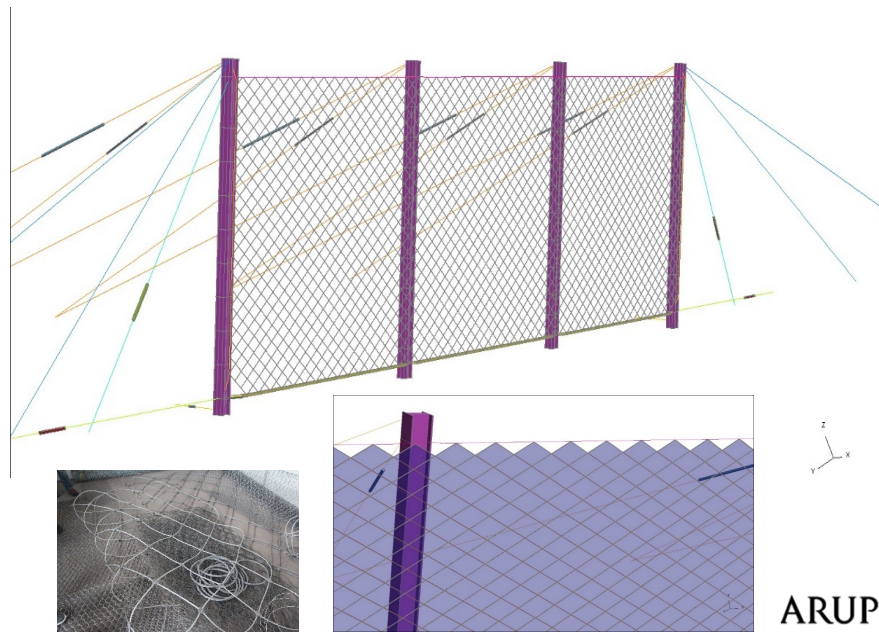
- A full-scale test carried out in Veltheim, Switzerland using Geobrugg barriers.
- Release of artificially mixed debris material along a 40 m, 30° flume



ARUP

The Veltheim Field Test Model

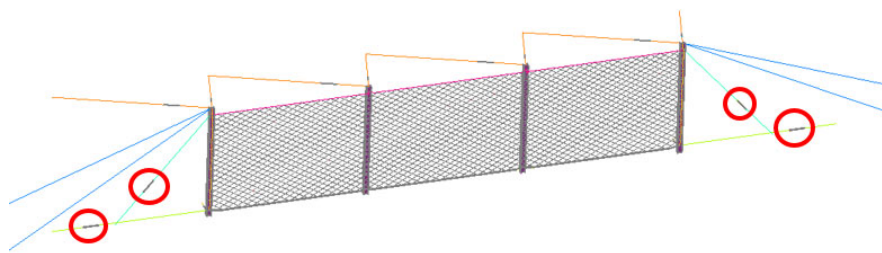
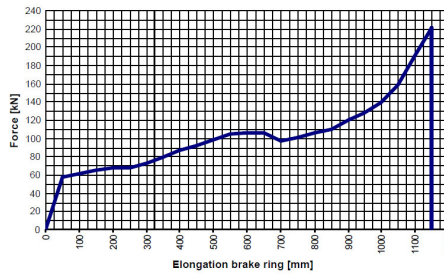
Model Setup – Flexible Barrier



ARUP

The Veltheim Field Test Model

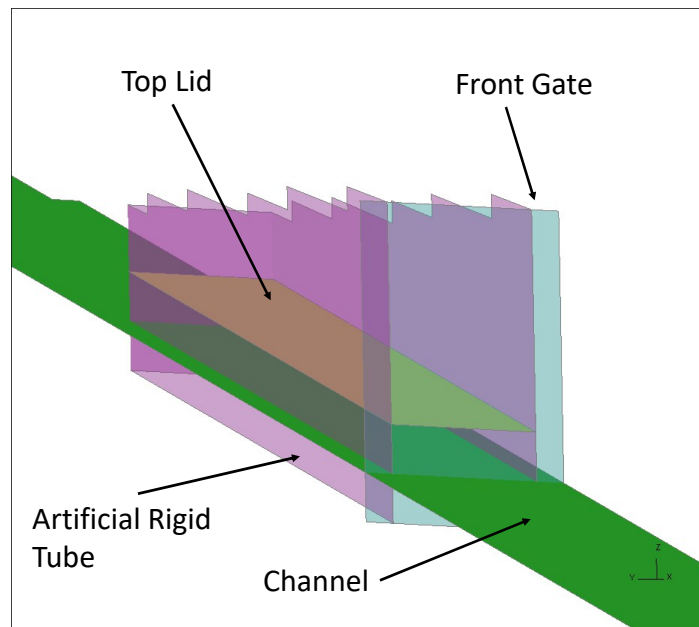
Model Setup – brake element



ARUP

The Veltheim Field
Test Model

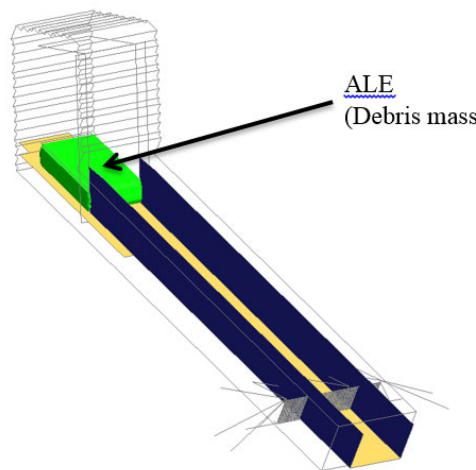
Model Setup – Debris Container



ARUP

The Veltheim Field
Test Model

Model Setup – Topography



- Channel Width = 8 m
- Length to barrier = 41 m
- Inclination = 30°
- Debris Density = 2085 kg/m³
- Contact Friction between channel base and debris = 25°
- Contact Friction between channel side and debris = 25°
- Internal Friction of debris = 20°

ARUP

The Veltheim Field
Test Model

Model Setup

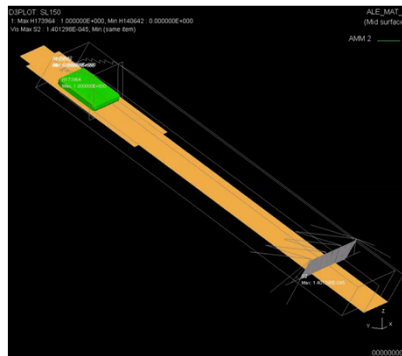
- Internal Friction Angle = 15°
- Basal Friction Angle = 15°

Action	Timesteps	Location of Debris
Gravity initialisation	0 – 1.0 s	Remained within container
Gate opening to 1 m above topography	1.0 – 2.0 s	Debris started to slide downward
Gate remained open	1.5 – 100.0 s	All debris flew out of the container

ARUP

The Veltheim Field
Test Model

Model Result

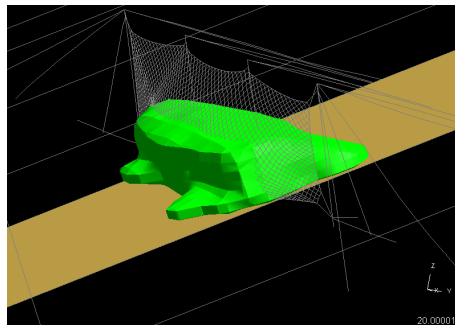


- Debris velocity closely resembled actual scenario

ARUP

The Veltheim Field Test Model

Model Result



DISPLOT: 84156

FILE: 84156

DATE: 2019

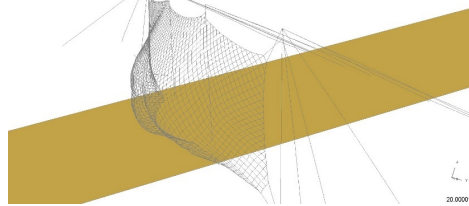


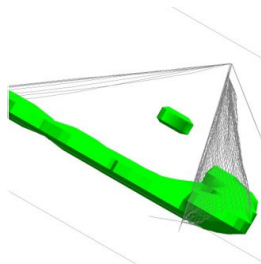
Fig. 8: Barrier after release 1.

ARUP

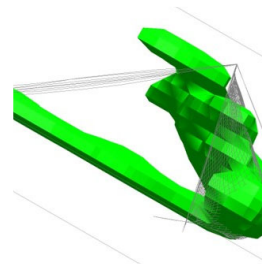
The Veltheim Field Test Model

Model Result

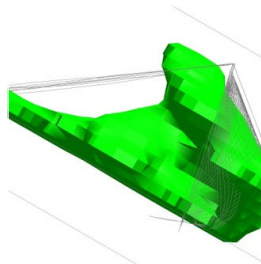
6.5s



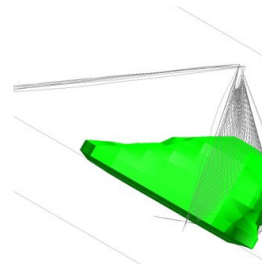
7.2s



8.1s



10.5s



ARUP

The Veltheim Field
Test Model

Debris Location and Time

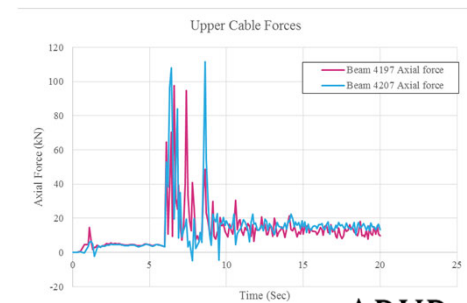
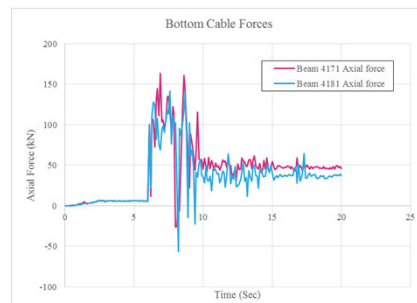
	Release	Post 1	Post 2	Post 3
x (m) distance from storage tank	0	11	21	31
t (s) (Actual Test)	0	1.54	2.82	3.8
t (s) (LS-DYNA)	0	1.8	2.8	3.5
Velocity (m/s) (Actual Test)		7.1	7.8	10.2
Velocity (m/s) (LS-DYNA)		6.1	10.0	14.3

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The Veltheim Field
Test Model

Cable Forces

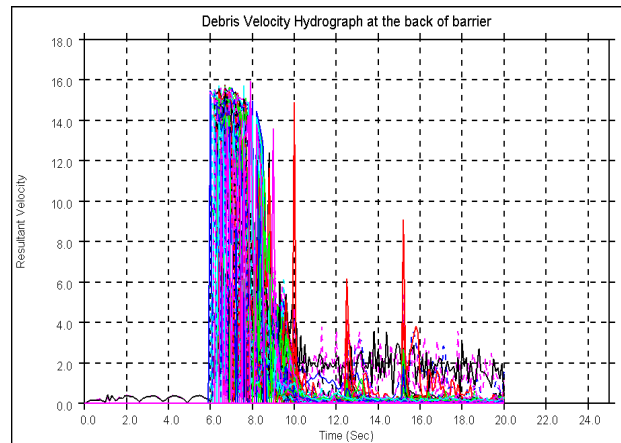
	Upper Cable	Lower Cable	Upslope Cable
Cable Forces in Actual Test (kN)	40	74	42
Cable Forces in LS-DYNA (kN)	111	163	65



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The Veltheim Field Test Model

Velocity behind the barrier

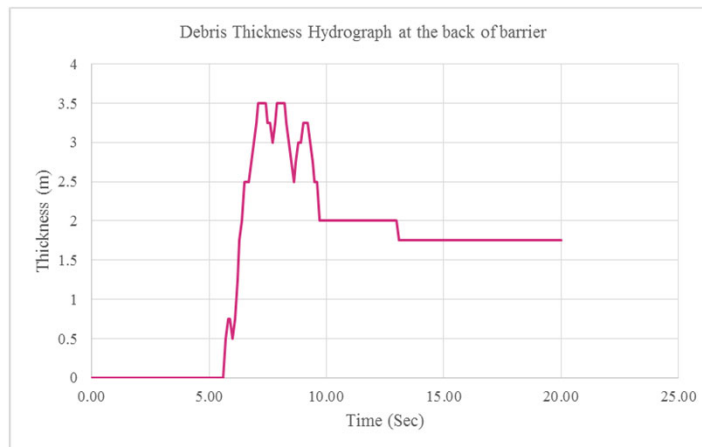


- The maximum velocities of debris recorded at the back of the barrier were approximately 15 to 16 m/s, which was comparable to the actual test results. The impact duration was approximately 2 sec.

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The Veltheim Field Test Model

Debris Thickness behind the barrier

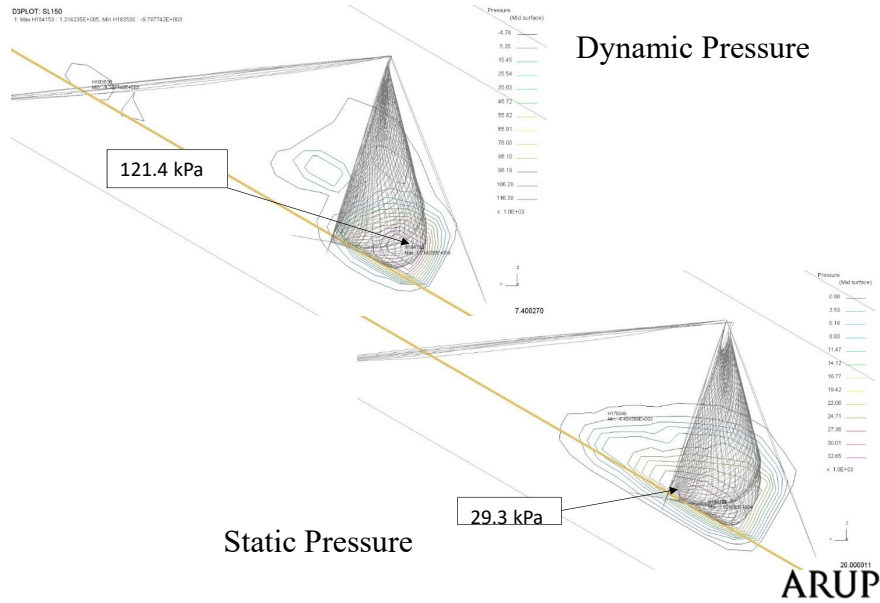


- The debris front reached the barrier and the debris thickness increased to 3.5 m in approximately 1.5 sec.
- After approximately 4 sec after impact the debris became static with a thickness of 1.75 m

ARUP

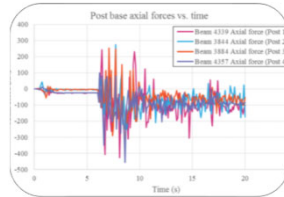
The Veltheim Field Test Model

Dynamic impact pressure and static pressure

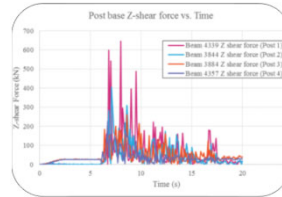


The Veltheim Field Test Model

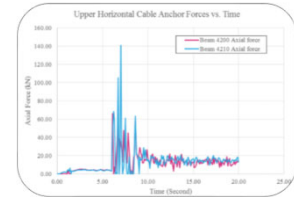
Plus more results....



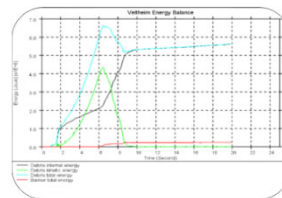
Post Base Axial Force



Post Base Shear Force

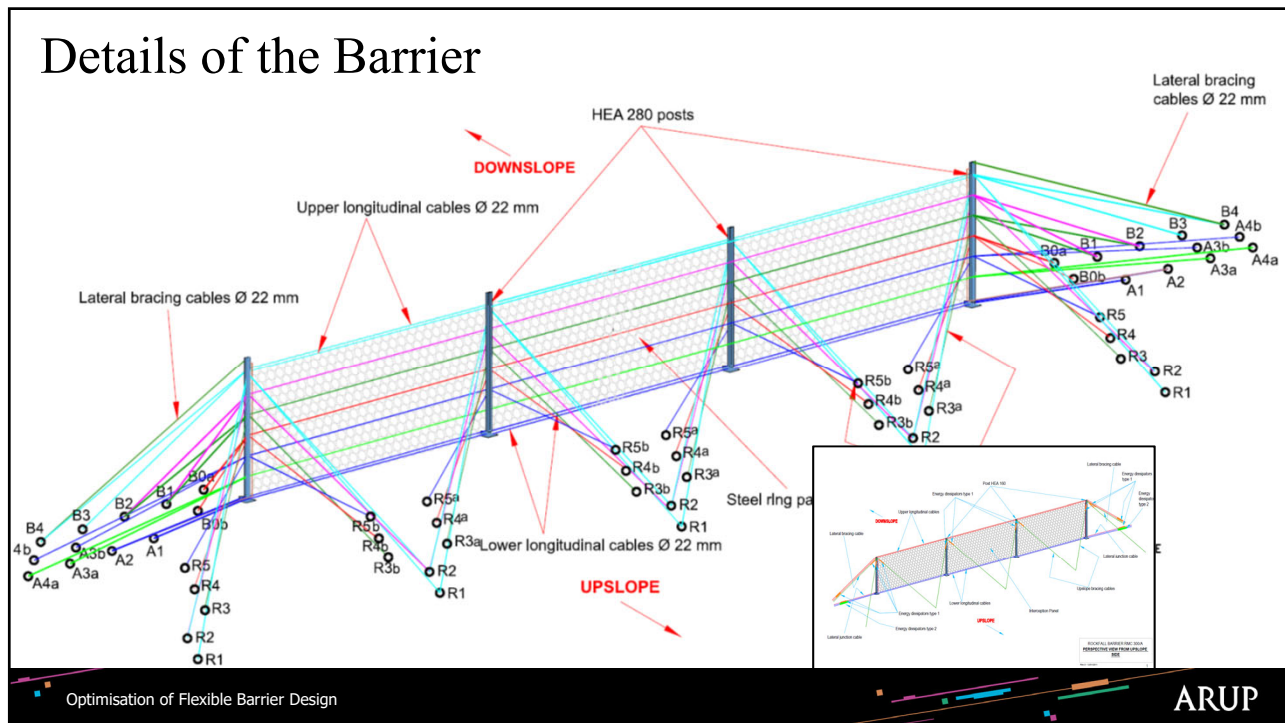
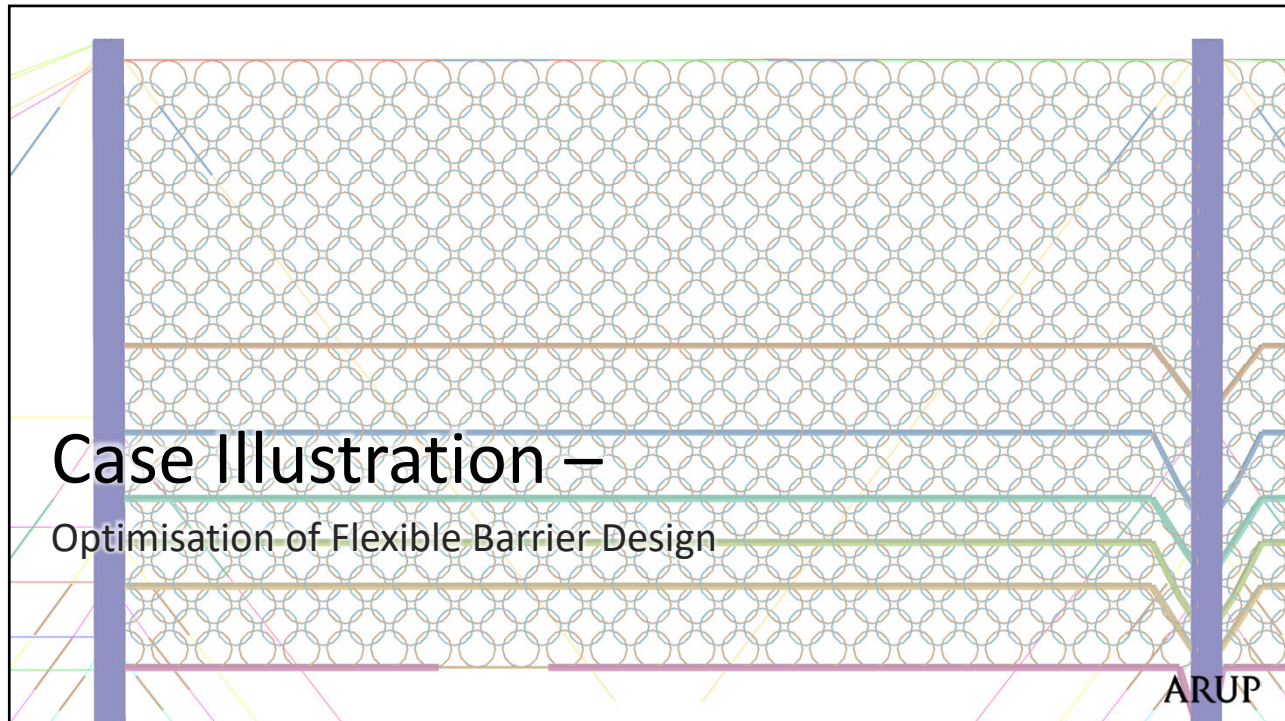


Horizontal Cable Anchor Force



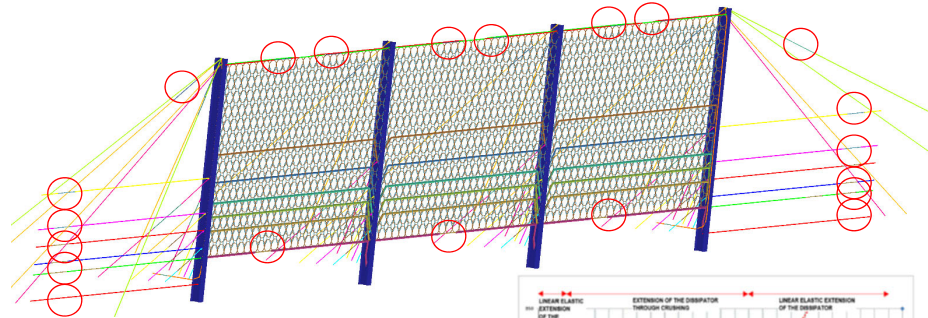
Energy Balance

ARUP

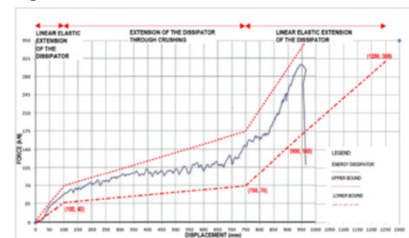


Brake Element (Energy Dissipators)

- Maximum load allowed per brake element = 305kN
- Maximum elongation at 305kN = 1250mm



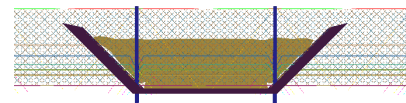
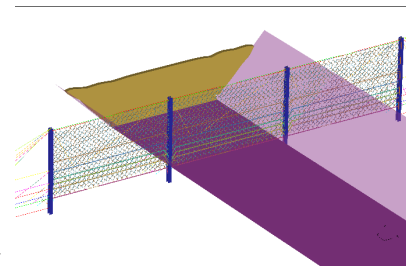
Location of brake elements along horizontal cable ropes

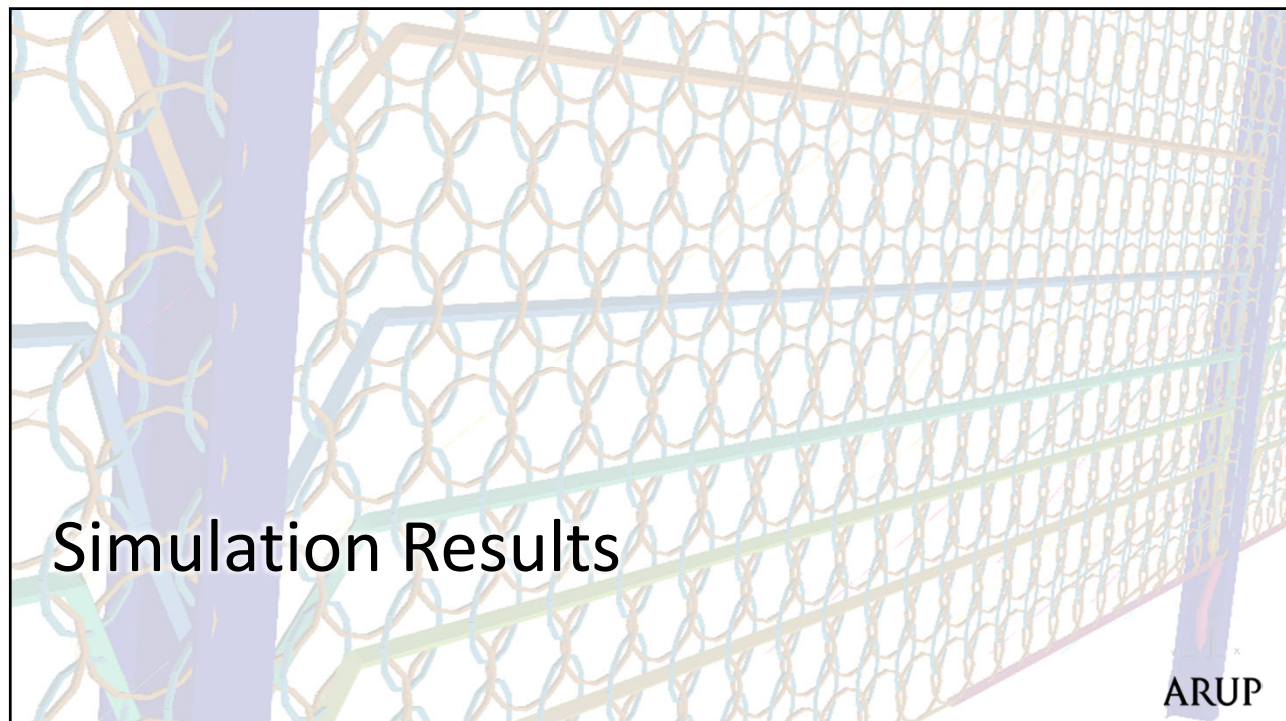
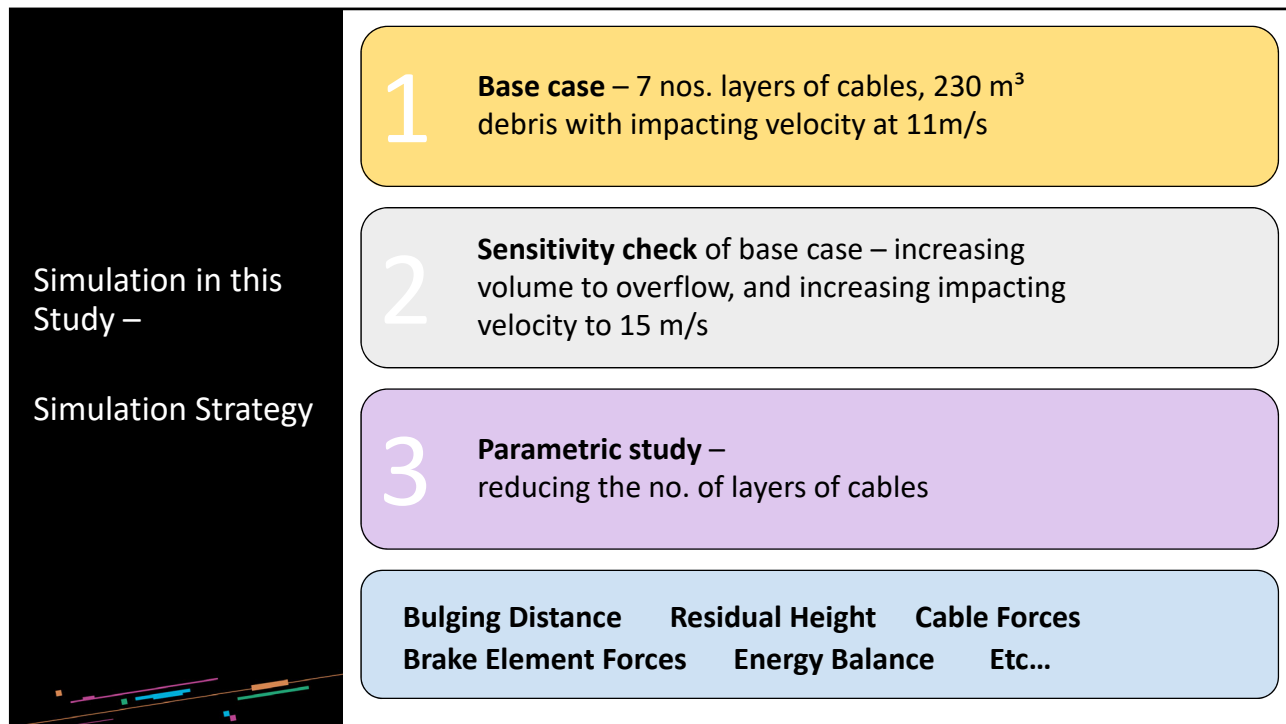


Load-deformation Curve

Methodology

- The flexible barrier is placed at 10 m away from debris source
- Apply gravity to the barrier and let it settle down
- Inject ~1m thick debris at specified speed (base case = 11m/s) and specified duration
- Record deformation and structural forces during the simulation





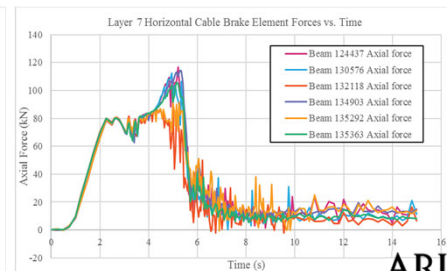
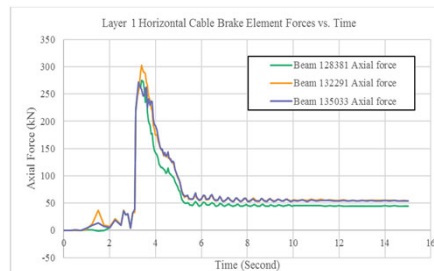
Simulation Results

Base Case

7 nos. layers of cables,
230 m³ debris with
impacting velocity at 11m/s

Brake element at horizontal cables

Layers	Number of Cables	Allowable tension force based on acceptance criteria (kN)	Recorded maximum tension force (kN)	Utilisation of brake elements (%)
Layer 1	6	1800	303	17
Layer 2	6	1800	304	17
Layer 3	6	1800	367	20
Layer 4	6	1800	347	19
Layer 5	4	1200	243	20
Layer 6	4	1200	228	19
Layer 7	2	600	117	20



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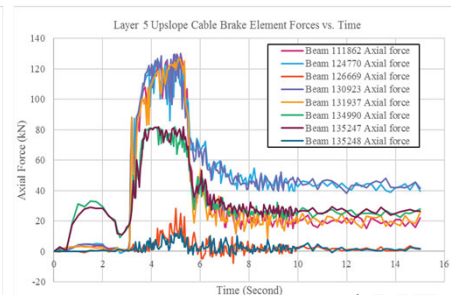
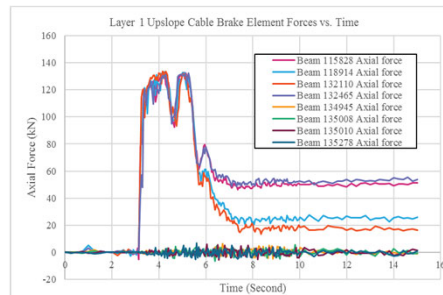
Simulation Results

Base Case

7 nos. layers of cables,
230 m³ debris with
impacting velocity at 11m/s

Brake element at upslope cables

Layers	Number of Cables	Allowable tension force based on acceptance criteria (kN)	Recorded maximum tension force (kN)	Utilisation of brake elements (%)
Layer 1	3	900	134	15
Layer 2	3	900	140	16
Layer 3	3	900	145	16
Layer 4	1	300	52	17
Layer 5	2	600	130	22



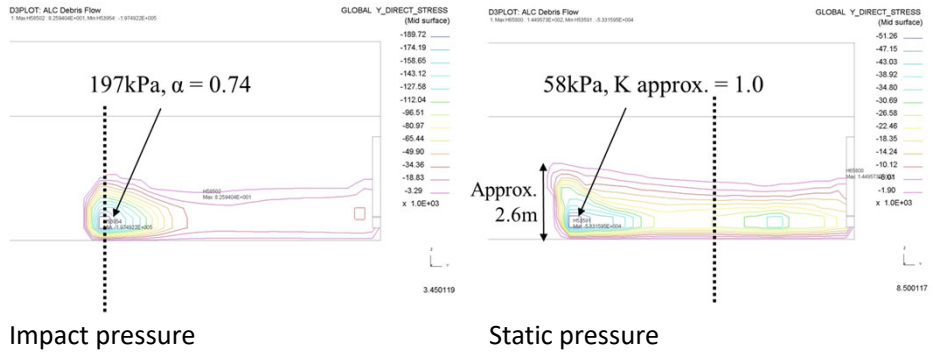
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Simulation Results

Base Case

7 nos. layers of cables,
230 m³ debris with
impacting velocity at 11m/s

Debris pressure acting on the barrier



$$p_d = \alpha \rho_d v^2 \dots\dots\dots (B.1)$$

where ρ_d = density of moving debris, taken to be 2,200 kg/m³ as a minimum
 v = velocity of moving debris hitting the barrier (m/s)
 α = dynamic pressure coefficient, taken to be 2.0

$$p_s = K d \rho_s g \dots\dots\dots (B.2)$$

where K = coefficient of earth pressure, taken to be 1.0
 d = depth below the upper surface of moving debris (m)
 ρ_s = density of the deposited debris, taken to be 2,200 kg/m³ as a minimum
 g = gravitational acceleration (m/s²)

Source: DN1/2012

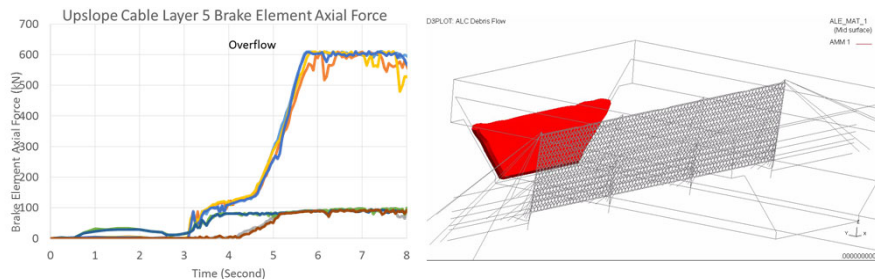


Simulation Results

Sensitivity Check

Increasing volume of
230 m³ to overflow, and
increasing impacting velocity to
15 m/s

- Brake element forces at horizontal cables are well within capacity, even for overflow @ 15m/s case, maximum utilisation is only **71%** at layer 7 (uppermost layer)

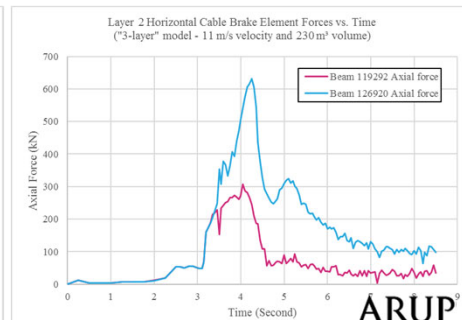
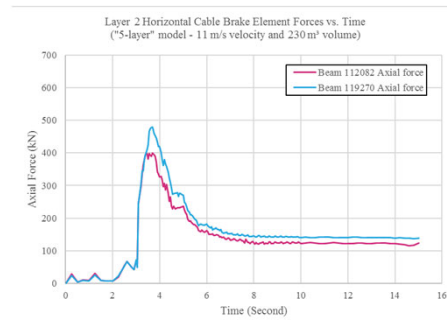


Simulation Results

Parametric Study

Reducing the no. of horizontal cables

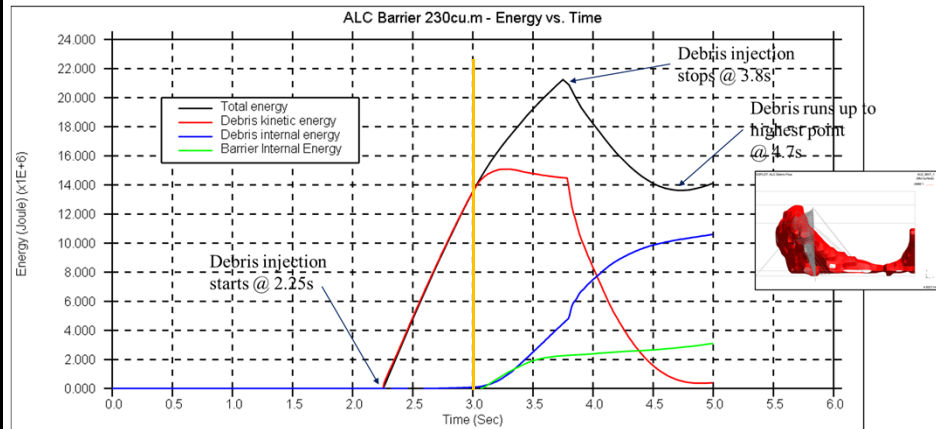
- Gradually reducing number of layers of horizontal cables from $7 > 5 > 3 > 2$
- Other configuration, including number of cables per layer remain the same
- All configuration can sustain 230 m^3 debris @ 11 m/s , except for “2 layers model”, for which the deformation exceeds the acceptance criteria



Discussion – Conservativeness of the Design

- Our Study shows there is high potential to use fewer layers of cables to sustain the same design debris flow event
- Debris-barrier interaction allows:
 - Slowing down of debris in subsequent surges
 - Additional energy could be dissipated within the retained debris mass e.g. internal turbulence
 - Reduce artificial conservativeness due to assumed impact pattern

Energy balance in LS-DYNA model



Barrier absorbed energy (BE) = 3,000 kJ

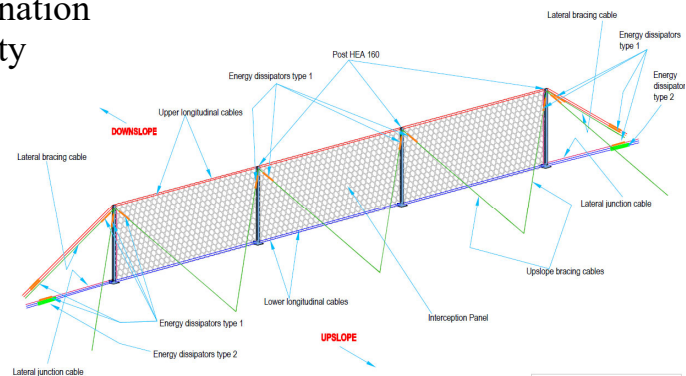
Debris Kinetic Energy at impact (KE) = 14,000 kJ

BE to KE Ratio = 20% only!

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More Study on Energy Balance of Barrier

- Similar debris flow interaction simulation on commercially available rock fall barrier
- 3,000 kJ Macaferri rock fall barrier
- Parameters to vary:
 - Channel inclination
 - Debris velocity



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ROCKFALL BARRIER RMC 300A
PERSPECTIVE VIEW FROM UPSLOPE
SIDE

More Study on
Energy Balance of
Barrier

Base Case

Base Case

Model ID	Slope (°)	Initial Velocity (m/s)	Debris Volume (m ³)	Debris Kinetic Energy at impact (KE) (kJ)	Max. Barrier Total Energy (BE) (kJ)	BE to KE Ratio (%)
F (Base case)	0	5.0	100	1060	120	11

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More Study on
Energy Balance of
Barrier

Phase 1

Phase 1 – Increasing Velocity

Model ID	Slope (°)	Initial Velocity (m/s)	Debris Volume (m ³)	Debris Kinetic Energy at impact (KE) (kJ)	Max. Barrier Total Energy (BE) (kJ)	BE to KE Ratio (%)
F (base case)	0	5.0	100	1060	120	11
N	0	7.5	100	2700	460	17
O	0	10.0	100	4900	1080	22

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More Study on
Energy Balance of
Barrier

Phase 2

Phase 2 – Increasing Slope Inclination

Model ID	Slope (°)	Velocity before impact (m/s)	Debris Volume (m ³)	Debris Kinetic Energy at impact (KE) (kJ)	Max. Barrier Total Energy (BE) (kJ)	BE to KE Ratio (%)
N	0	9.0	100	2700	460	17
Q	10	10.0	100	3900	1140	29
K	15	9.1	100	2850	1030	36
R	30	10.1	108	2450	2040	83

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Conclusions

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Benefits of LS-DYNA in landslide modelling

- A thorough **3D back-analysis of landslides** can help to determine the probably causes of failure and recommend the necessary follow-up actions.
- LS-DYNA can be a useful tool for **detailed forensic investigations**, such as the analysis of the likely mode and sequence of failure and diagnosis of the causes of the landslide.
- In the event of landslide incident where the landslide debris hit an existing flexible barrier, **debris-flexible barrier interaction** can be modelled using LS-DYNA accurately.
- The coupled analysis enables detailed investigation of the **structural forces and energy balance** involved in the impact process.

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Remarks

- Dynamic analysis is required for dynamic problem.
- Pseudo-static approach or over-simplification of the model can render in overconservative design.
- With accurate topographical information, advanced computational model predicts the path of debris flow (trajectory) and time of arrival. The designer can position and test the mitigation works at the strategic (most effective) locations.

ARUP

Thank you

HKIE TRANSACTIONS, 2018
<https://doi.org/10.1080/1023697X.2018.1462106>



Advanced numerical analysis of landslide debris mobility and barrier interaction

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ABSTRACT

Mitigation of natural terrain hazards through the use of flexible and rigid barriers has become a common type of geotechnical work in Hong Kong. The current design approach for these structural countermeasures typically involves separate debris mobility modelling and structural analyses of barriers subject to pseudo-static impact loadings. This practical approach, however, could not realistically account for the dynamic debris-barrier interaction. With a view to better capturing the response of barriers under debris impact, effort has recently been devoted to developing an advanced numerical technique to model debris flows, barrier structural responses and the impact dynamics in a coupled manner. This paper presents some recent advances made in establishing the numerical technique of coupled analysis using a three-dimensional finite-element computer code LS-DYNA. The methodologies of modelling the landslide debris mobility, the large-deformation non-linear behaviour of a flexible barrier under impact and the coupled analysis of debris-barrier interaction are introduced. Back analyses of selected landslide events and debris impact tests of flexible barriers for verification of the computer models are discussed. The coupled analysis enables detailed investigation of the energy balance involved in the impact process. Preliminary results of this energy analysis are also presented.

ARTICLE HISTORY

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KEYWORDS

Debris mobility; flexible barrier; debris-barrier interaction; energy balance; LS-DYNA; finite-element modelling

A.K.C. Cheung, J. Yiu, H.W.K. Lam & E.H.Y. Sze (2018) “**Advanced Numerical Analysis of Landslide Debris Mobility and Barrier Interaction**” HKIE Transaction Theme Issue on Landslides and Debris Flow – Theory and Design, Mitigation, Stabilisation and Monitoring, 2018, Hong Kong Institution of Engineers.

HKIE Workshop on Numerical Modelling for Design of Flexible Debris-resisting Barriers

Organized by

Geotechnical Division, Hong Kong Institution of Engineers

Working Group on Application of Innovative Technology in Geotechnical Engineering

Supporting organization

Department of Civil & Environmental Engineering, Hong Kong Polytechnic University

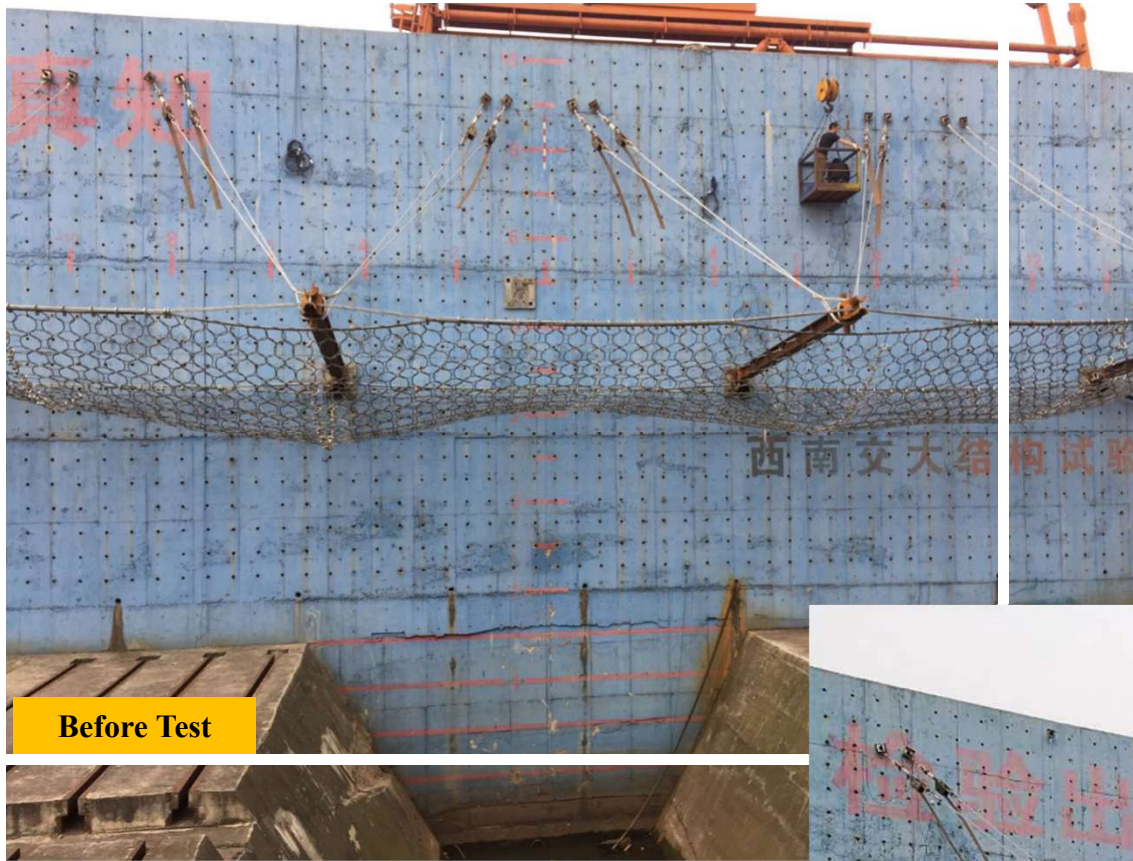


NIDA-MNN Modelling for Design of Flexible Barriers

Prof. SL Chan, Dr. ZH Zhou, Dr. YP Liu
Mr. JW He and Dr. L Zhao

16th April, 2019

The Hong Kong Polytechnic University



Content

1 Introduction

2 Fundamentals of Nonlinear Theory

3 Main Components of Flexible Barriers

4 Typical Configurations of Flexible Barriers

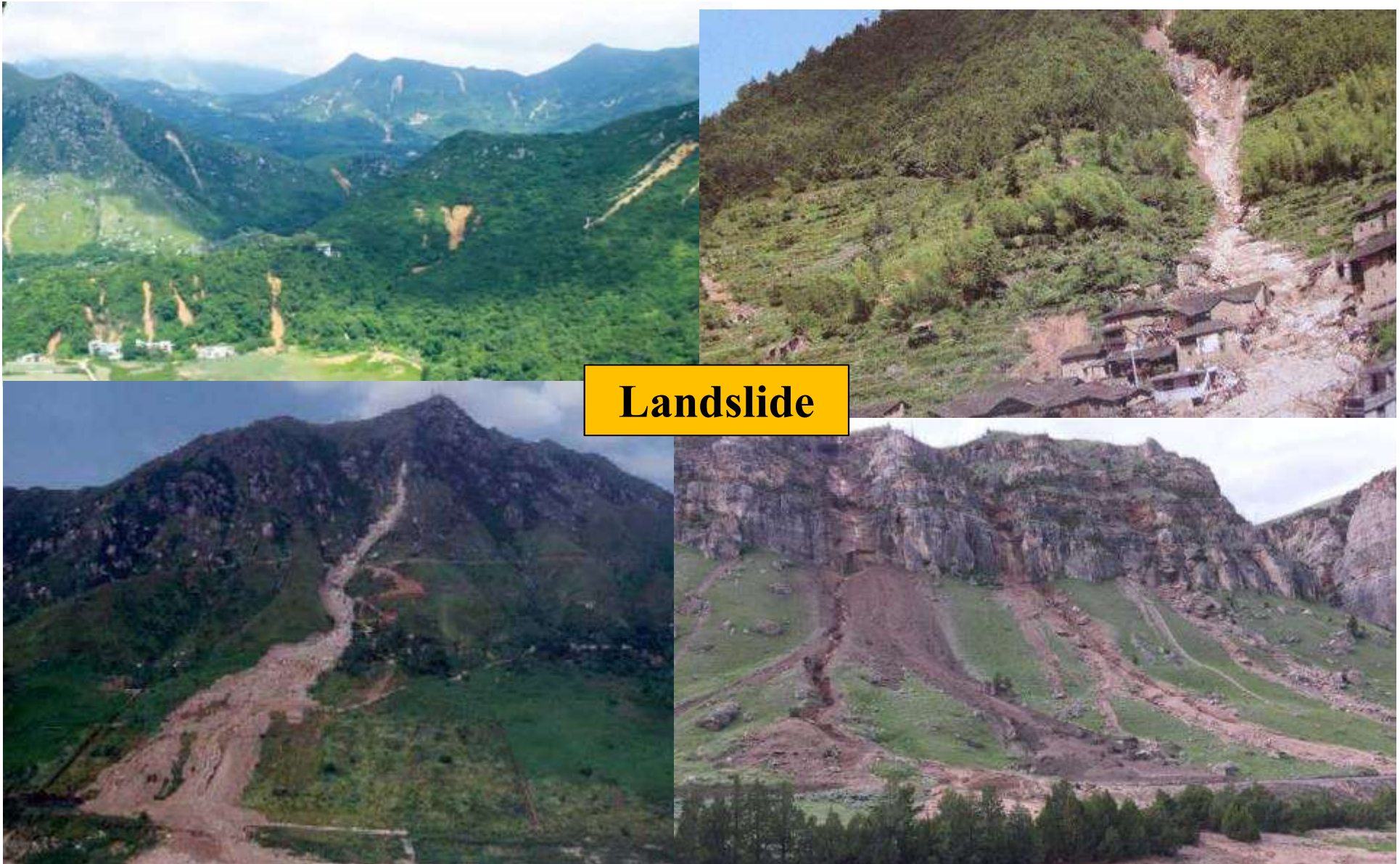
5 Development of Energy Absorbing Devices

6 Analysis & Design of Flexible Barriers

7 Full-scale Test of Flexible Barriers

8 Conclusions

What's flexible barrier? - *Protection system against landslide*



What's flexible barrier? - Protection system against rockfall

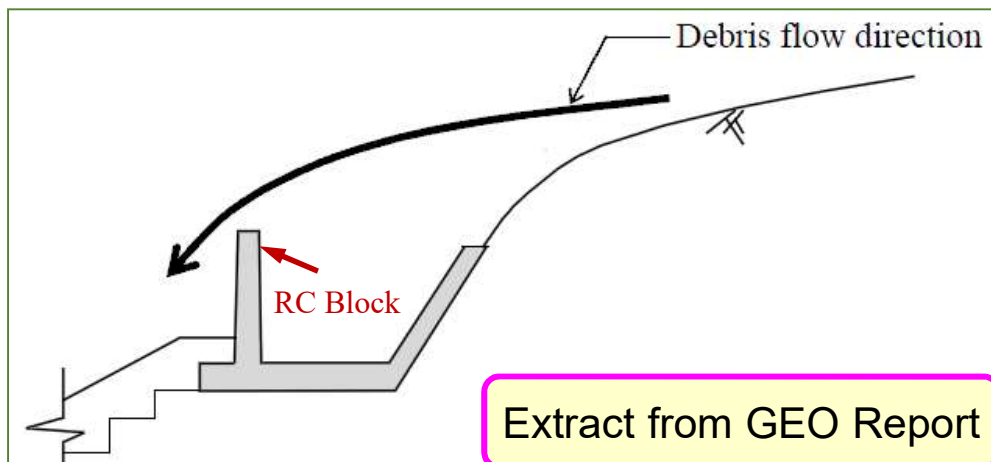


Rockfall



Why flexible barrier?

- Old Solution: Rigid Barrier
 - Difficulty in Construction;
 - Higher Impact Load;
 - Higher Cost;
 - Environmental Impact;
 - Opaque & Less Aesthetics;
 - ...

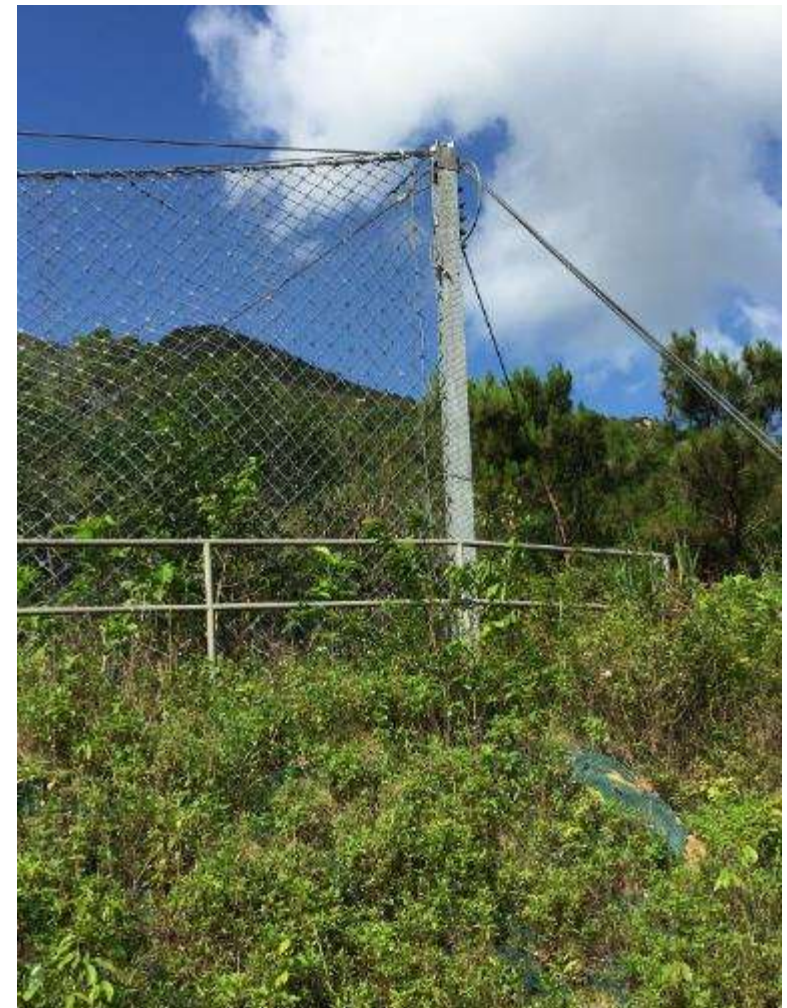
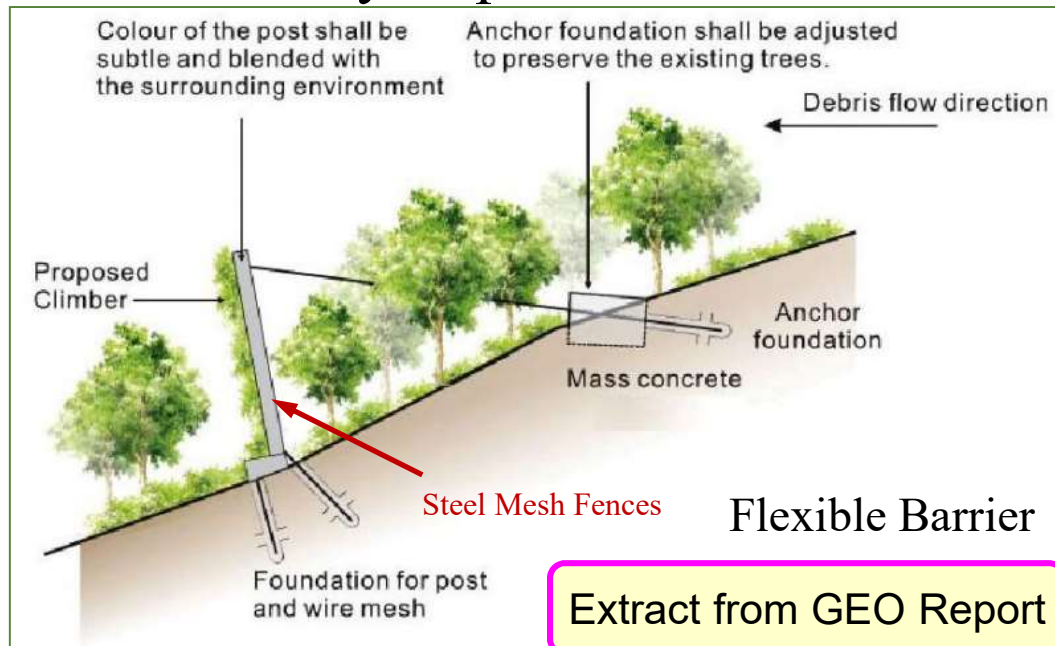


Extract from GEO Report



Why flexible barrier?

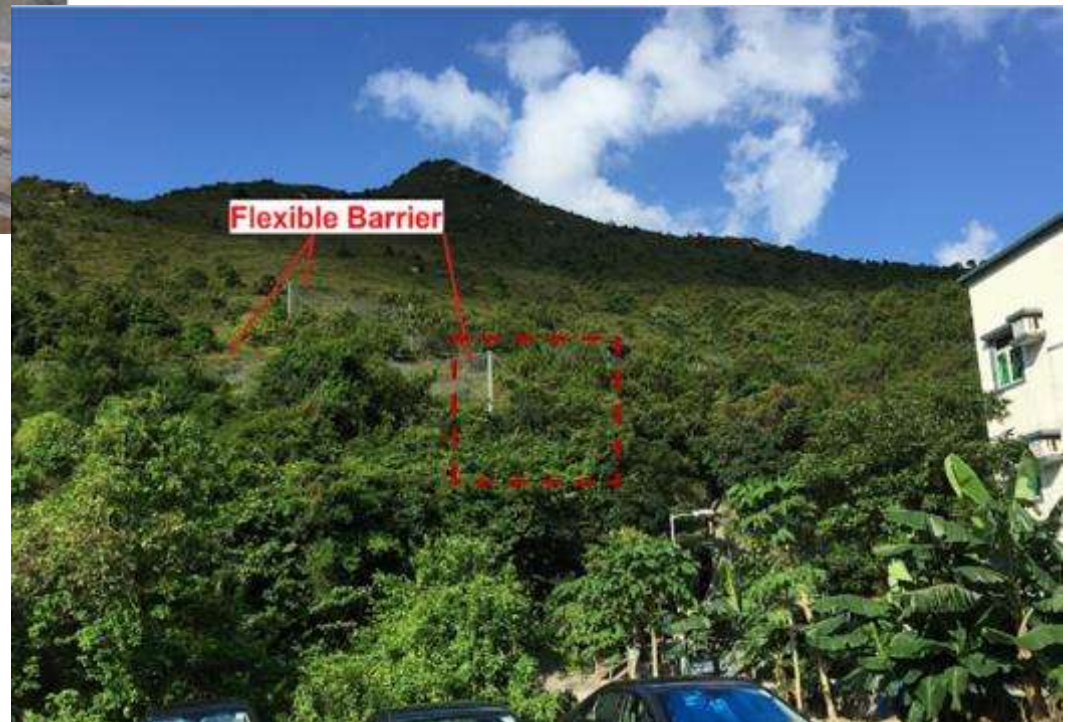
- **New Solution: Flexible Barrier**
 - Easy & Fast Construction;
 - Lower Impact Load; 以柔克剛
 - Lower Cost;
 - Less Environmental Impact;
 - Transparent & Good Aesthetics;
 - Easy Repair...



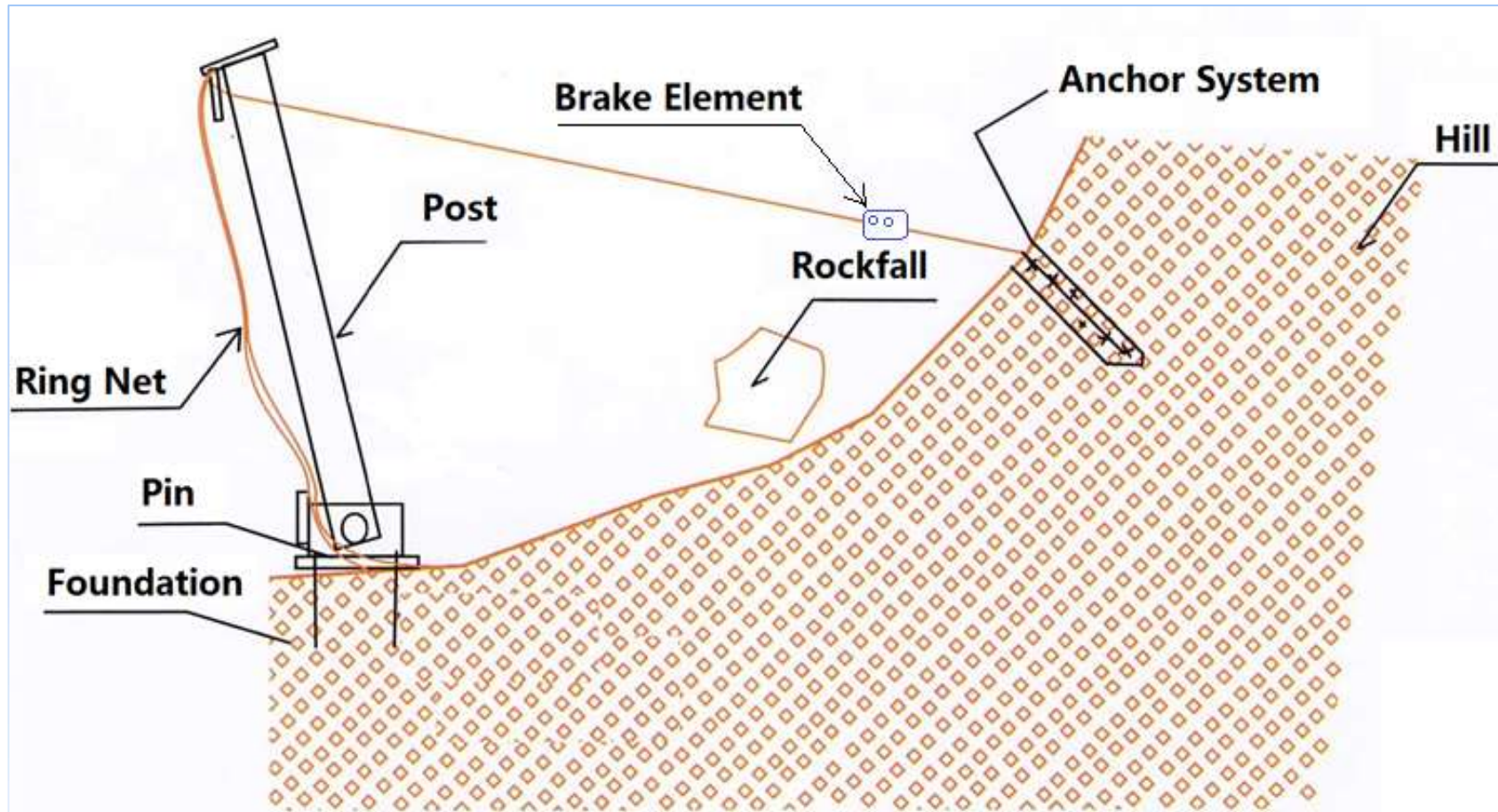
Why flexible barrier?



Protection Barrier Rigid vs. Flexible



What's flexible barrier?



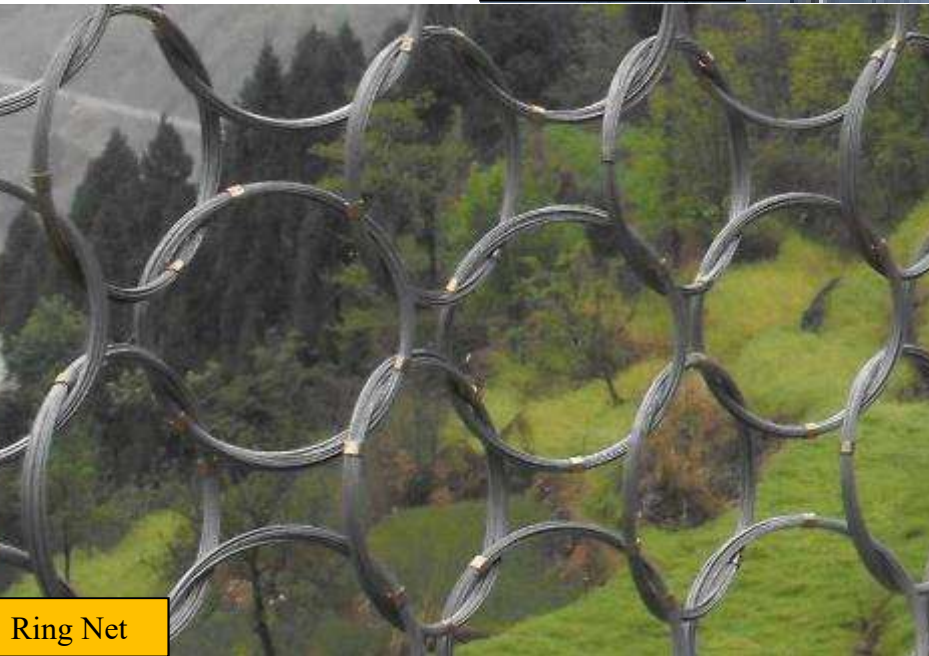
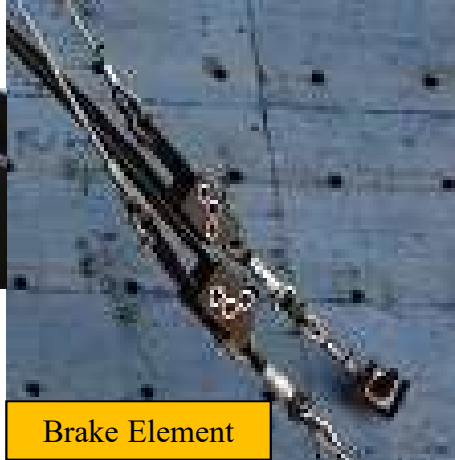
Section view of a typical flexible barrier system

What's flexible barrier?

Shackle



Brake Element



Ring Net



Flexible Barrier System

Why conduct this research in Hong Kong?

- Rocks falling from slopes can be very dangerous to buildings, vehicles in highways and pedestrians along hill side. Normally engineers build rigid or flexible barriers to capture these rocks against their collision with other buildings, vehicles or humans.
- Foreign proprietary products used in Hong Kong (**High cost, Black box, Unsafe, Standard product but not tailor-made, ...**)
- This project is aimed to develop new a **energy absorbing device (EAD)**, which is one of the major component of flexible barrier system. → *Absorb >70% Impact Energy*

Why conduct this research in Hong Kong?

- Energy absorbing device – *Brake Element*
 - Major component of the flexible barrier system;
 - High energy absorbing capacity;
 - Made of metal and mounted on steel cables;



Why conduct this research in Hong Kong?

- Energy absorbing device – patented and expensive, limit the application of flexible barrier system in Hong Kong.



Proprietary products in market:

- Geobrug
- Maccaferri
- Trumer
- Isotop
- Tubosider
- EI Montagne



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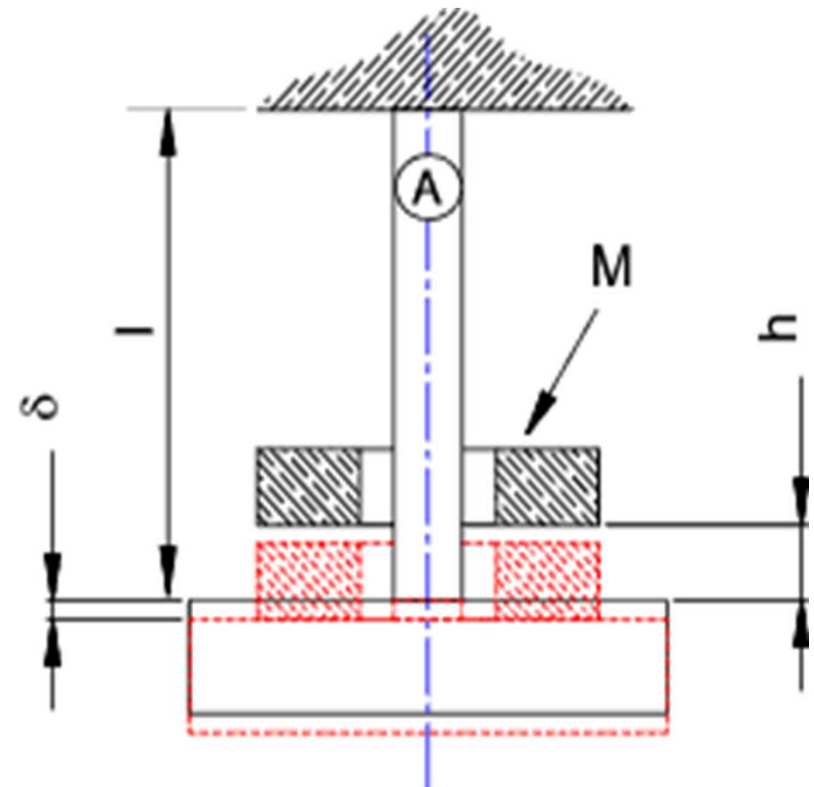
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Linear Impact deflections and stresses under gravitational loads

- Consider a loading shown below with a ring Mass M (kg) of weight $W= M.g$ (N) dropped through a distance “ h ” onto a vertical bar with stiffness as a spring with a stiffness of k (N/m).
- The support bar has a length l (m),
Area A (m^2)
Modulus of elasticity E (N/m^2)



$$W(h + \delta_{max}) = \frac{1}{2} (k\delta_{max})\delta_{max}$$

$$\delta_{max}^2 - \frac{2W}{k} \delta_{max} - 2 \left(\frac{W}{k} \right) h = 0$$

$$\delta_{max} = \frac{W}{k} \sqrt{\left(\frac{W}{k} \right)^2 + 2 \left(\frac{W}{k} \right) h}$$

$$\delta_{st} = \frac{W}{k} = \frac{WI}{AE}$$

$$\delta_{max} = \delta_{st} + \sqrt{(\delta_{st})^2 + 2\delta_{st}h}$$

$$\delta_{max} = \delta_{st} \left(1 + \sqrt{\left(1 + \frac{2h}{\delta_{st}} \right)} \right)$$

The resultant maximum force is

$$P_{max} = k \delta_{max}$$

and the resultant maximum stress is

$$\sigma_{max} = P_{max}/A$$

$$\sigma_{max} = \sigma_{st} \left(1 + \sqrt{\left(1 + \frac{2h}{\delta_{st}} \right)} \right)$$

For the calculation of the stress due to a sudden load, $h = 0$

$$\sigma_{max} = 2\sigma_{st}$$

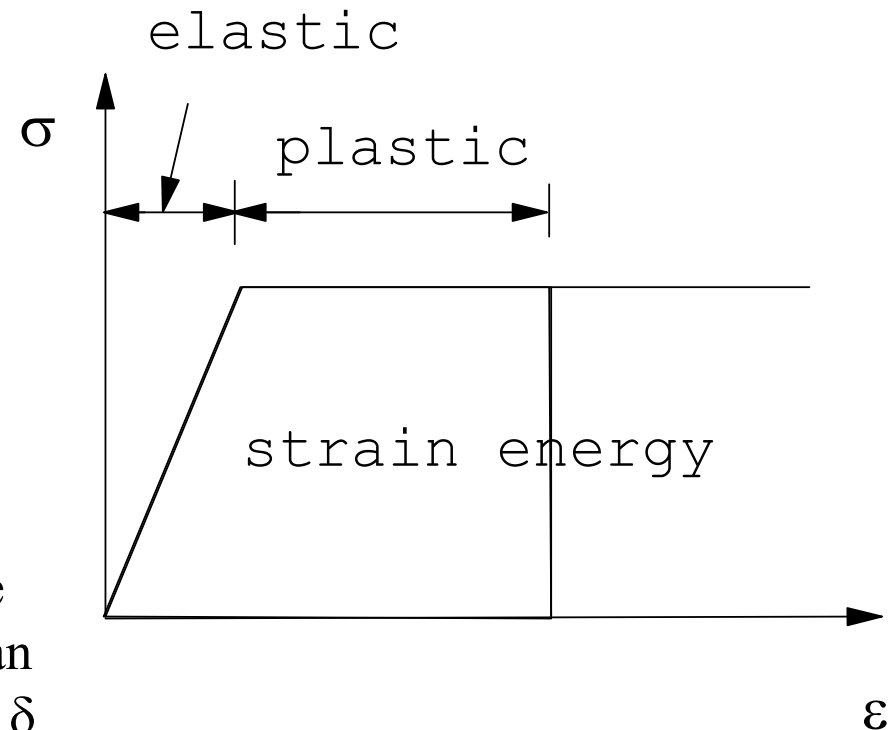
2 Fundamentals of Nonlinear Theory

- As can be seen in the above simple equations , the weight impact onto the support to make it deform until all of the potential energy has been absorbed, either in elastic or plastic range.
- The equations above compute the initial maximum deformation for the most highly stressed condition.

$$mgh = \frac{1}{2}mv^2 = \int \sigma \varepsilon dV$$

$$A = \pi r^2 \quad F = \frac{mgh}{\delta}$$

So, we have less force for larger displacement and a flexible barrier produce less reactions on supports or foundation than a rigid barrier which has smaller deflection δ



2 Fundamentals of Nonlinear Theory

20

A key feature of flexible barrier system is that it is light yet they can absorb high impact energy through the large elasto-plastic deformations and sliding node action.

This is achieved by sliding motion of nodes or element connection, the displacement of the cable net and the activation of energy dissipating devices mounted on the connecting cables.



Flexible Barrier Analysis

- Energy absorbing mechanism:
 Plastic + large elastic deformation
- Three-dimensional nonlinear analysis
 → *Geometrical and material nonlinearity*
- Large deflection analysis + Contact analysis
- Debris flows load → *Force vs. Energy design*
- Brake element model → *from Test*
- Sliding ring element → *Ring net*
- Sliding cable element → *Steel rope*

FORCE DESIGN OF ROCKFALL BARRIER

- The external forces, sum of previous **static forces** on net + **dynamic forces** on net multiplied by an amplification factor, will be applied onto the net and check for any breakage in the element as indicated by elongation greater than the maximum elongation of every element. Automatically plastic strain is allowed.

ENERGY DESIGN OF ROCKFALL BARRIER

- For a typical barrier system, the kinetic energy E of debris flows or falling rock and the total strain energy U of the barrier system can be given as below:

$$E = (1/2) mv^2 \quad \text{- Kinetic energy}$$

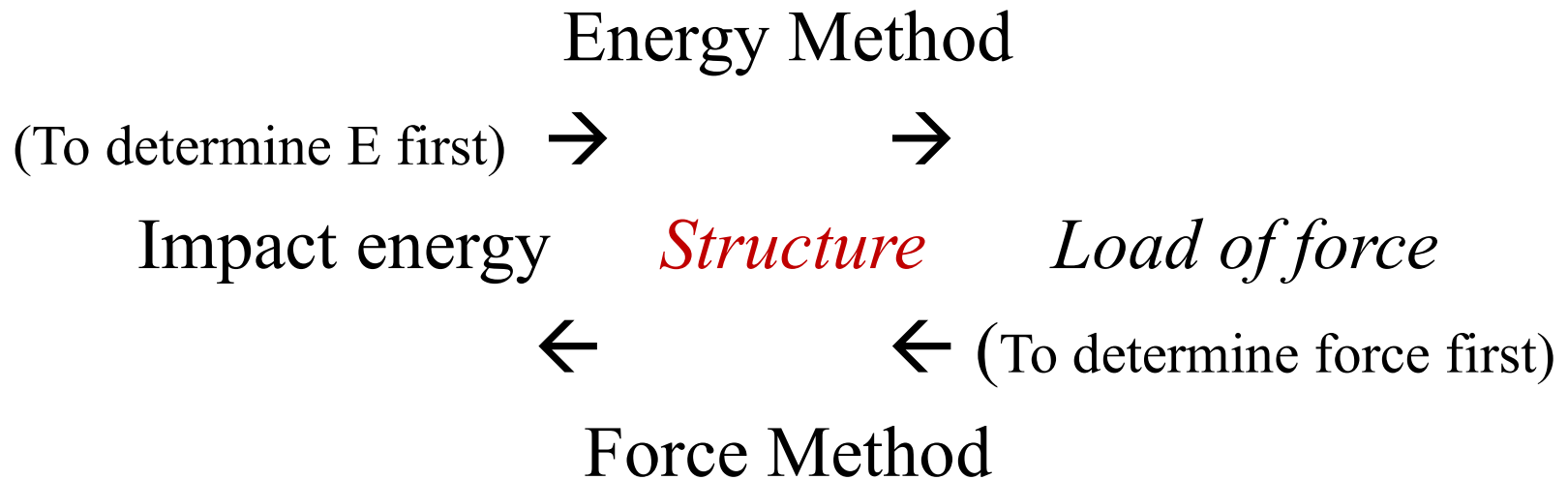
$$U = U_b + U_c + U_r \quad \text{- Total strain energy}$$

in which, m is mass of debris flows or falling rock; v is initial velocity of debris flows or falling rock; U_b , U_c and U_r are strain energy of brake elements, cables and net ring, respectively.

- The design criteria of barriers safely undergoing specified dynamic load may be described as:

$$U \geq E$$

Energy vs. Force Methods



Energy vs. Force Methods

- Energy is a simple and convenient indicator, but not all components reach their maximum energy absorption capacities simultaneously.

→ *Cannot simply sum up energy capacities of all components as system capacity*

- Force method is more direct and able to cater for uneven force distribution.

→ *The magnitude of force is unknown.*

($Ft = mv$, t is unknown, so F is unknown)

Assume load pattern →

Increase loads to achieve design energy

$$U \geq E$$

Content

1 Introduction

2 Fundamentals of Nonlinear Theory

3 Main Components of Flexible Barriers

4 Typical Configurations of Flexible Barriers

5 Development of Energy Absorbing Devices

6 Analysis & Design of Flexible Barriers

7 Full-scale Test of Flexible Barriers

8 Conclusions

Nida-MNN – A product of Nida family (*BD Reference: S0884*)

- NIDA-MNN is specially developed for nonlinear analysis of cable structures with Moving Node Net, such as rockfall barriers, debris flow barriers.
- NIDA-MNN provides an unified and user-friendly interface to assist the engineers to design a flexible barrier system like conventional steel structures.
- Unlike the commercial FE software using solid element to simulate flexible barrier, NIDA-MNN uses advanced beam-column element which leads to significant saving of modelling and computational time.

Nida-MNN – A product of Nida family (BD Reference: S0884)
BD Approval Letter of Nida-MNN

YOUR REF 來函編號:
OUR REF 本署編號: 56 in BD GR/OA/71 STR(203)
FAX 傳真號碼: 2626 1762
TEL 電話: 3162 3021
 www.bd.gov.hk

Date rec'd

Action	Copy	Date to file
		30 November 2016

Mr. Lau Chi Kin
 c/o Sun Hung Kai Architects and Engineers Ltd
 22/F, Sun Hung Kai Centre,
 30 Harbour Road,
 Hong Kong

Dear Sir,

**Application for Renewal of Prior Acceptance of Computer Program
 NIDA-MNN (Version 2013)
 (Large Deflection Analysis of Cable Net)**

I refer to your application and document dated 3 October 2016, 12 October 2016 and 25 October 2016 regarding the renewal of prior acceptance for the above computer program.

2. Based on your assessment of the computer program, I hereby grant my renewal of prior acceptance of its use in submissions made under the Buildings Ordinance for the validity period listed below and subject to the conditions stipulated in paragraphs 3 to 6.

Program Title	BD Reference Number	Valid Until
NIDA-MNN (Version 2013) (Large Deflection Analysis of Cable Net)	S0884	24 November 2019

BD Approval Letter of a Project Designed by Nida-MNN

17 MAY 2016

YOUR REF 來函編號:
OUR REF 本署編號: BD 3/9226/14
FAX 傳真號碼: 2845 1559
TEL 電話: 2626 1461
 www.bd.gov.hk

Date rec'd

Action	Copy	Date to file
		11 May 2016

LAU Chi Kin
 22nd Floor,
 Sun Hung Kai Centre,
 30 Harbour Road,
 Wanchai, Hong Kong.

Dear Sir,

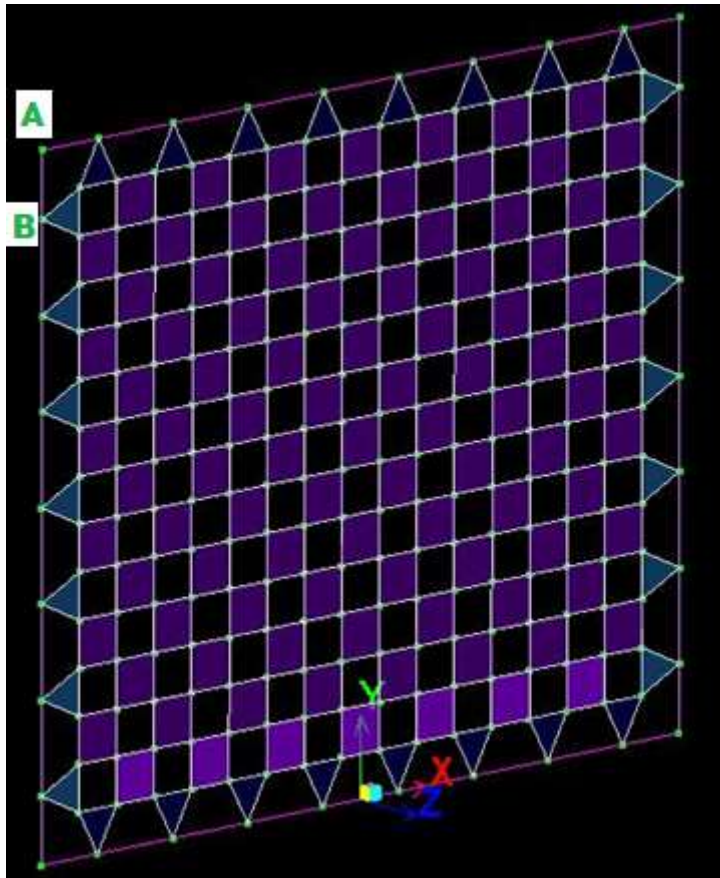
**King Sau Lane, Area 4, Tuen Mun - TMTL
 515 (formerly TM misc 271)**

I refer to your application received on 3 March 2016 for approval of proposals in respect of Foundation (Mini-Piles), Foundation (Socketed Steel H-Piles), Pile Cap and Flexible Barrier.

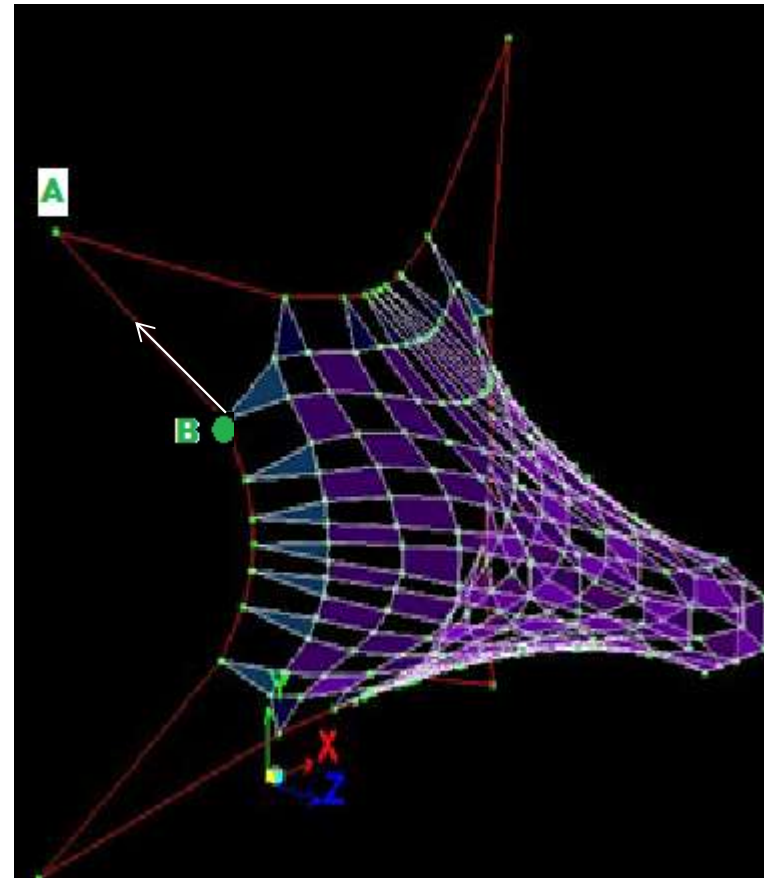
2. Your submission of plans has been checked under the curtailed check system announced in Practice Note for Authorized Persons, Registered Structural Engineers and Registered Geotechnical Engineers ADM-19. On this basis, I am satisfied that your submission is fundamentally acceptable and may be approved.

Handwritten notes: 039, 18/5/16, Prof. Chan

Computer modeling Moving node algorithm

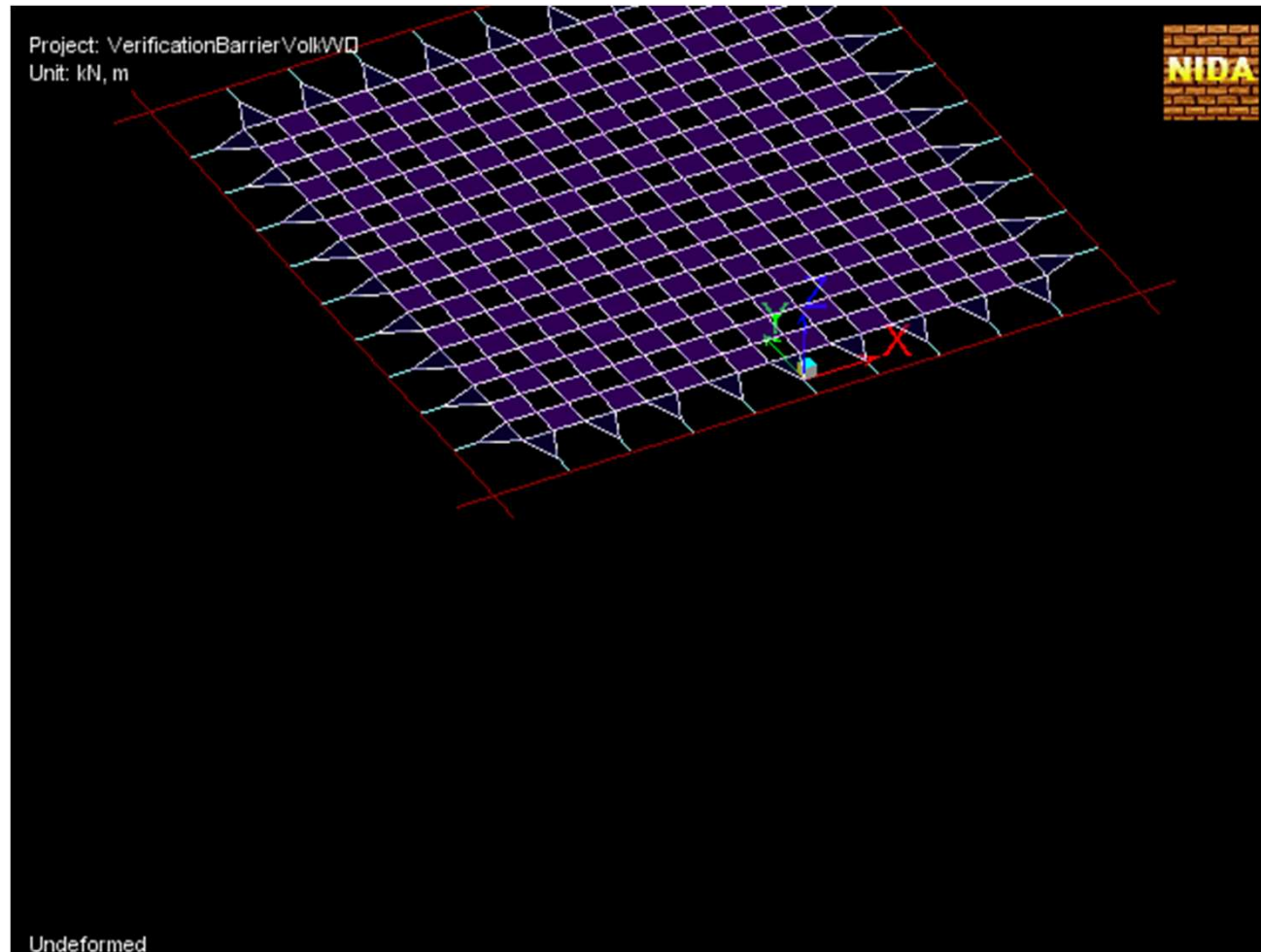


Before impact of rockfall



After impact of rockfall

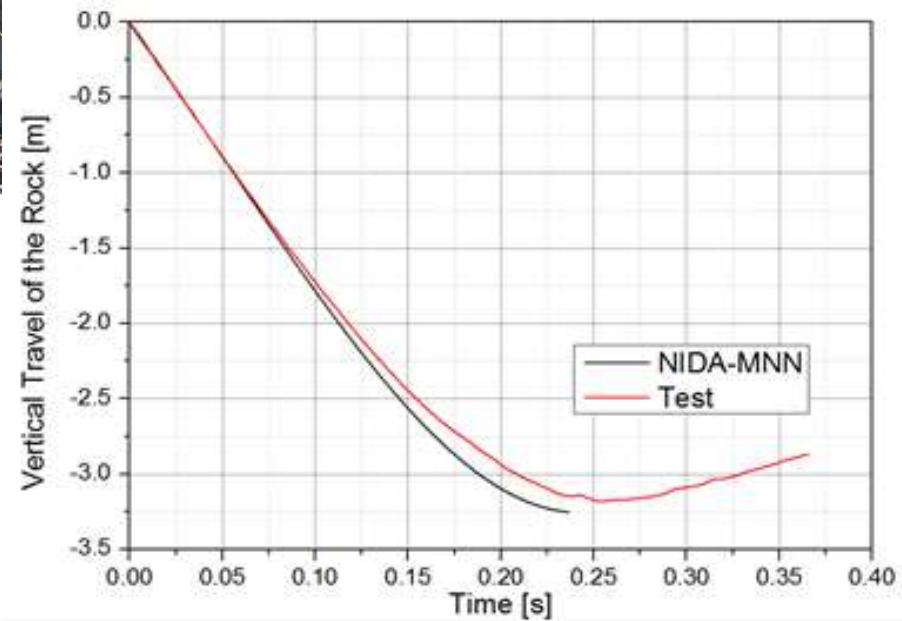
Numerical Simulation: Rockfall



Test and Simulating Curve

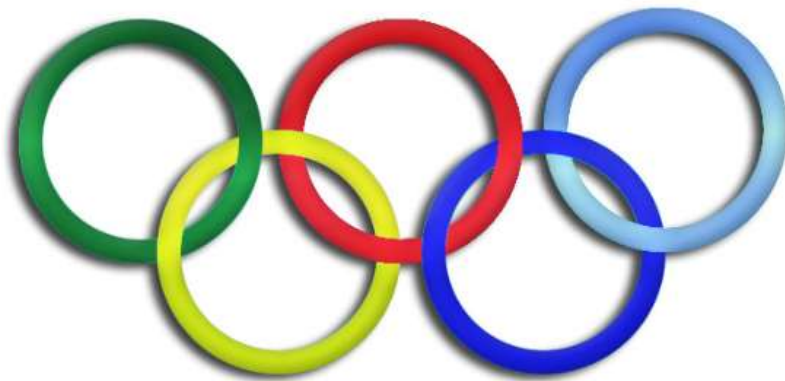
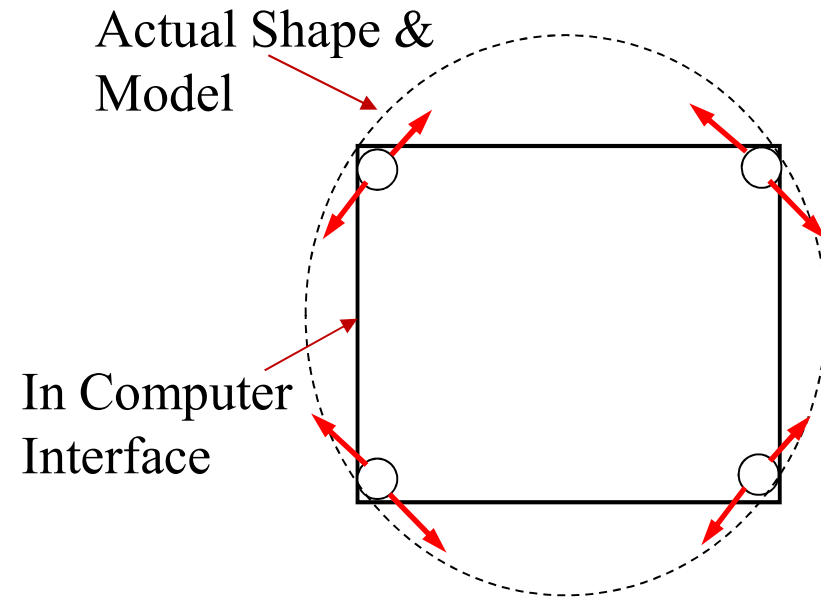


VolkWein



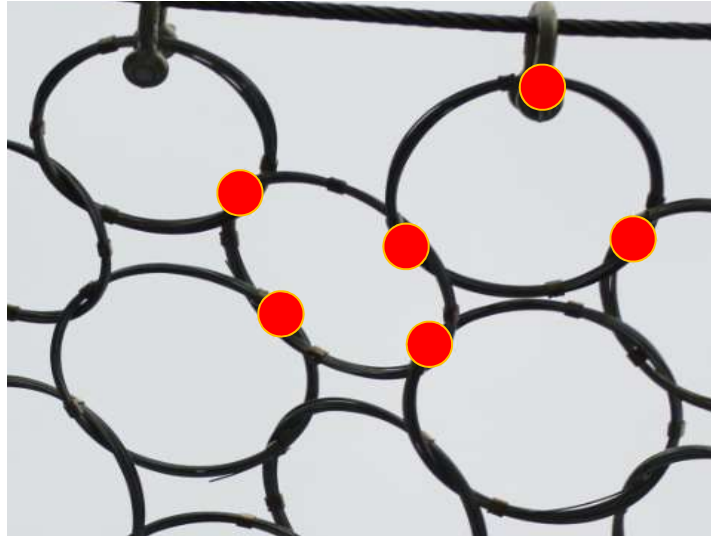
Modeling of Ring Net

- Each ring net connect at 3 to 4 points
- Connection point between every two ring nets is moveable
- Modeled by a new develop element considering contact behavior
- Friction force is considered

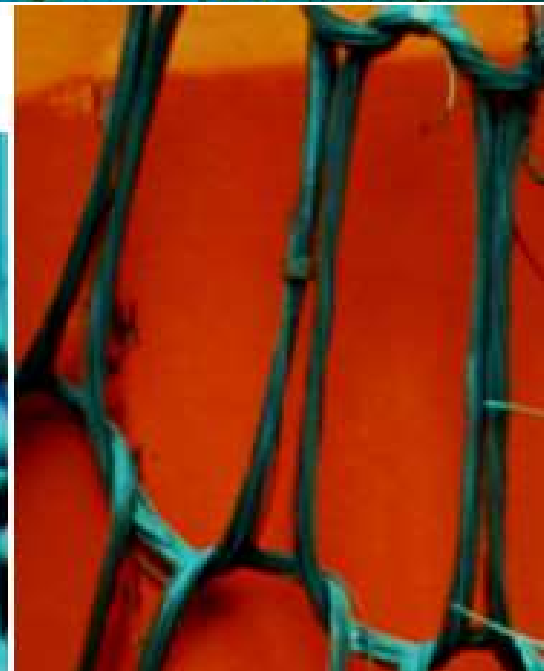


6 Analysis & Design of Flexible Barriers

Before sliding

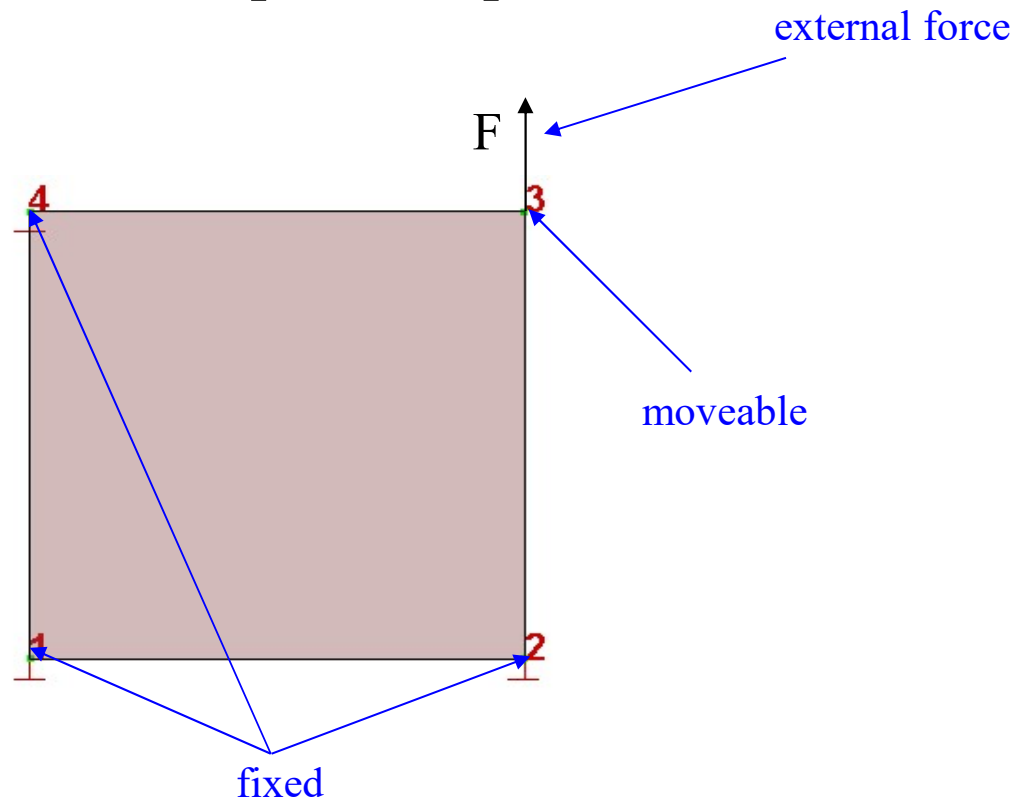


After sliding



Modeling of Ring Net

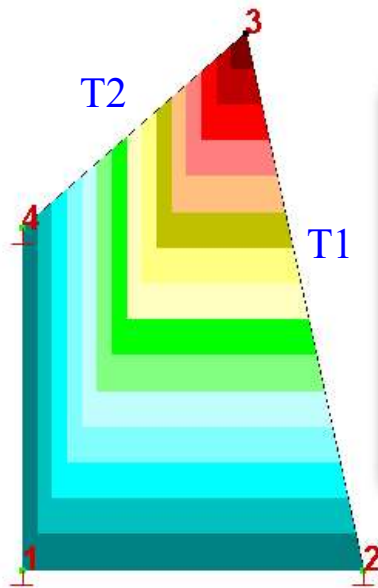
- Sliding ring element – a simple example



Simple example of sliding ring element

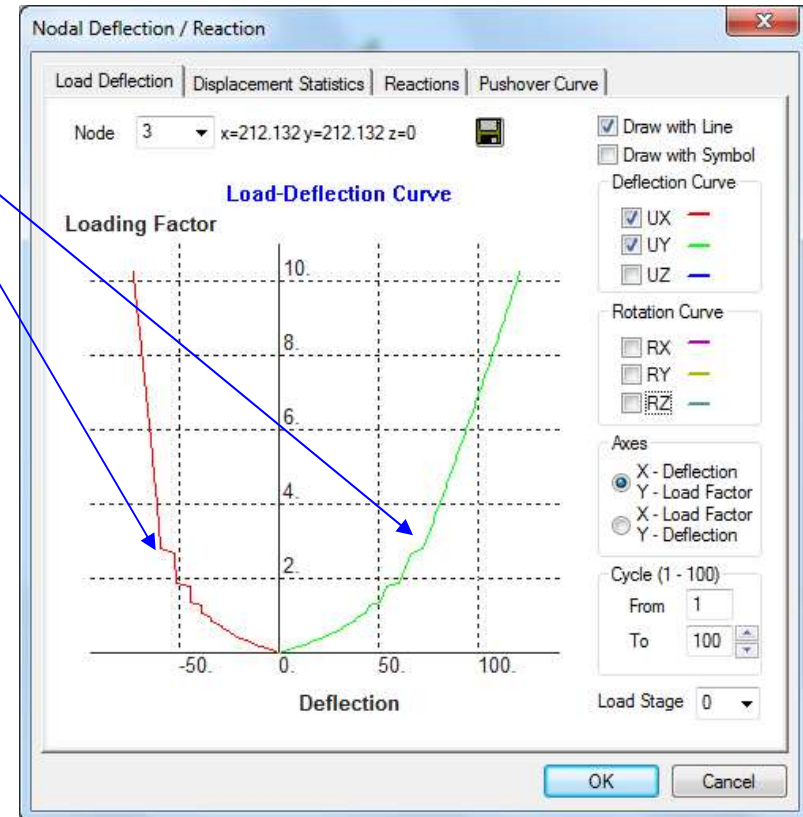
Modeling of Ring Net

Sliding



Displacement	
Node No.	3
DISP-X	-7.333e+001
DISP-Y	1.212e+002
DISP-Z	0.000e+000
ROT-X	0.000e+000
ROT-Y	0.000e+000
ROT-Z	7.876e-001

Jump due to friction



$$\text{Tension force } T1 = \text{Tension force } T2 + \text{Frictional force}$$

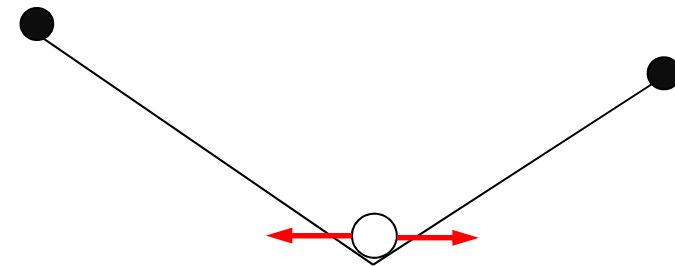
Deformed Shape of Ring Cable Element

Load-Deflection Curve

Modeling of Cable Rope

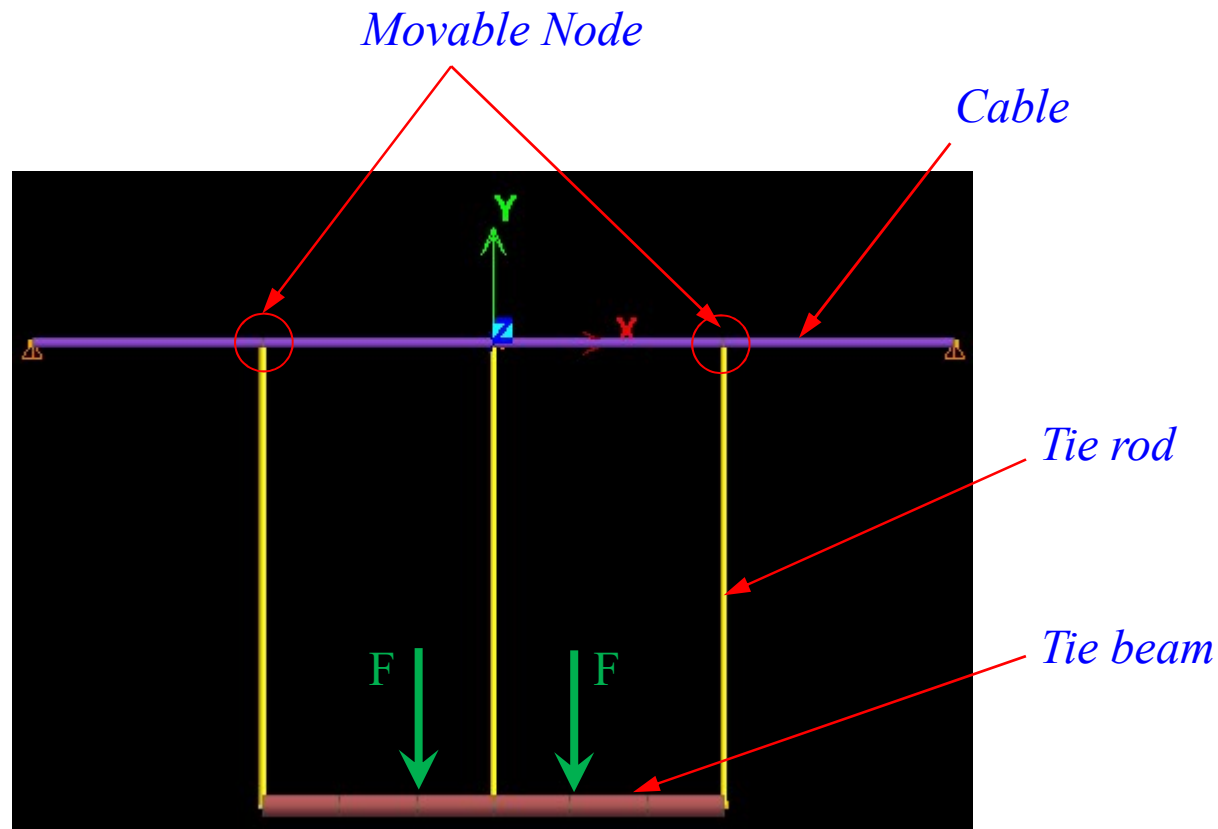
- Several segments allowed
- Connection point between rope and ring net is moveable
- Modeled by a new develop element considering contact behavior
- Friction force is considered
- Brake elements at any one or two segments

- General Node
- Sliding Node

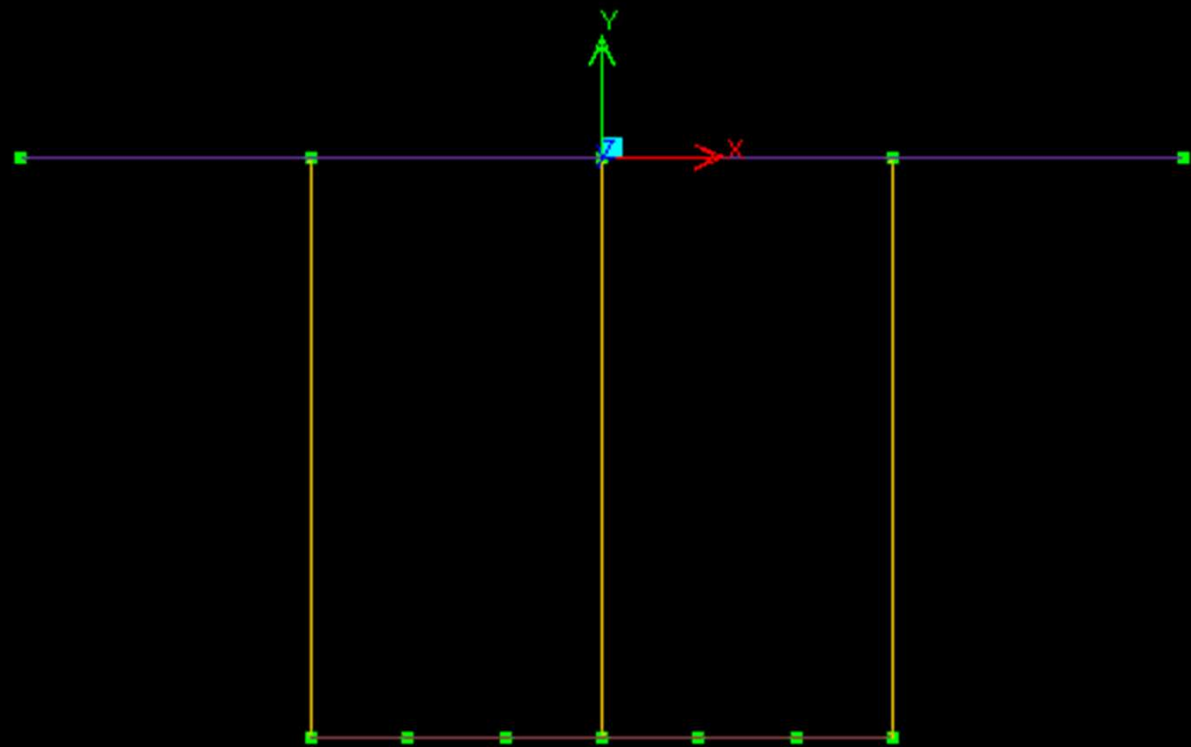


Modeling of Cable Rope

- Sliding cable element – a simple example



Project: 2Csuspend □
Unit: kN, mm

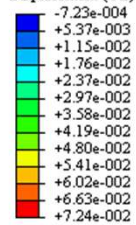


Undeformed

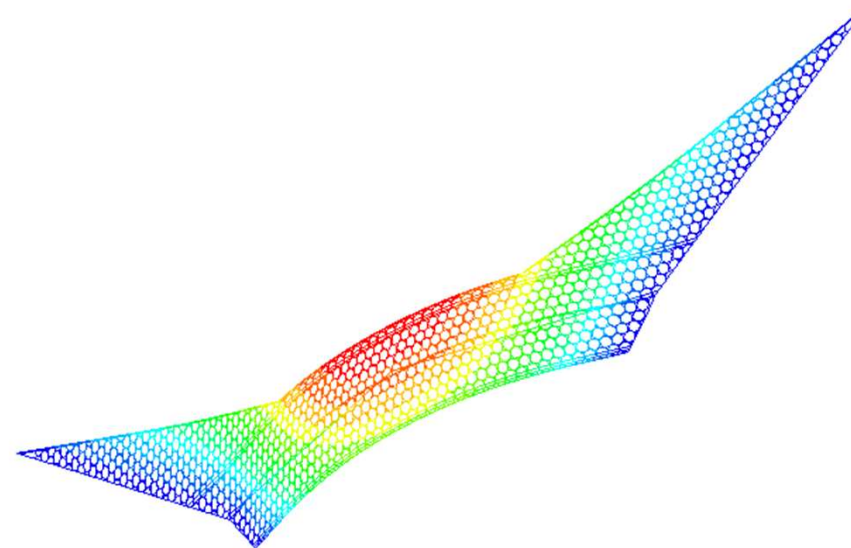
Numerical Simulation of Barrier under Debris Flow – Force Approach

Project Title: Flexible barrier model v3.1

Displacement (UZ)



2016-09-02 16:51



Loading Assessment

Loading of Energy

For rock falling: $m v^2 / 2 = m g h$

For debris flow: $< m v^2 / 2$

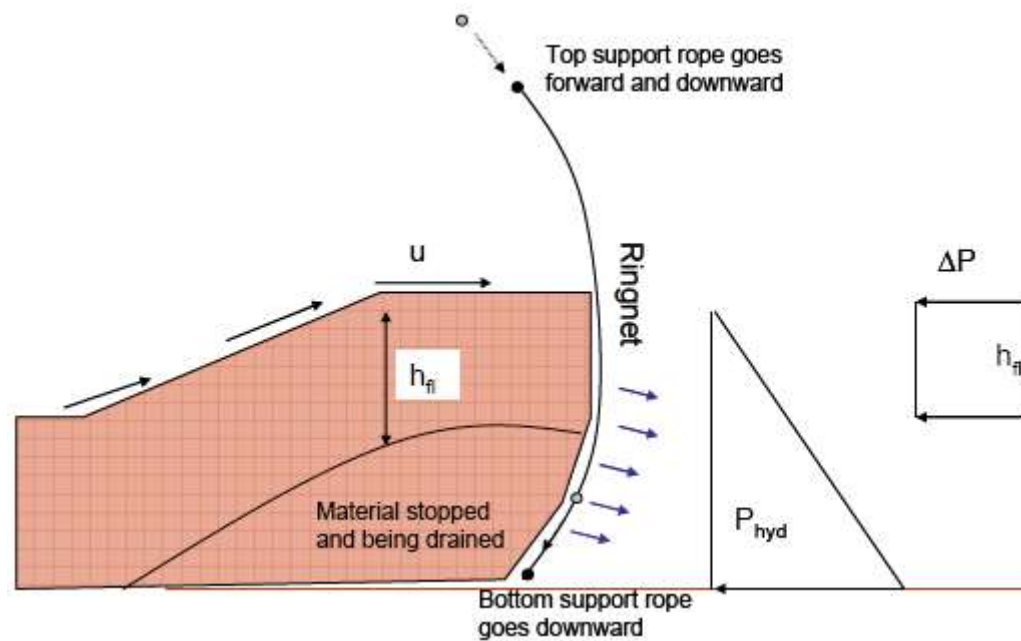
Loading of impact pressure

For rock falling: ???

For debris flow: $= \alpha \rho v^2$

Debris Flow – Force Approach

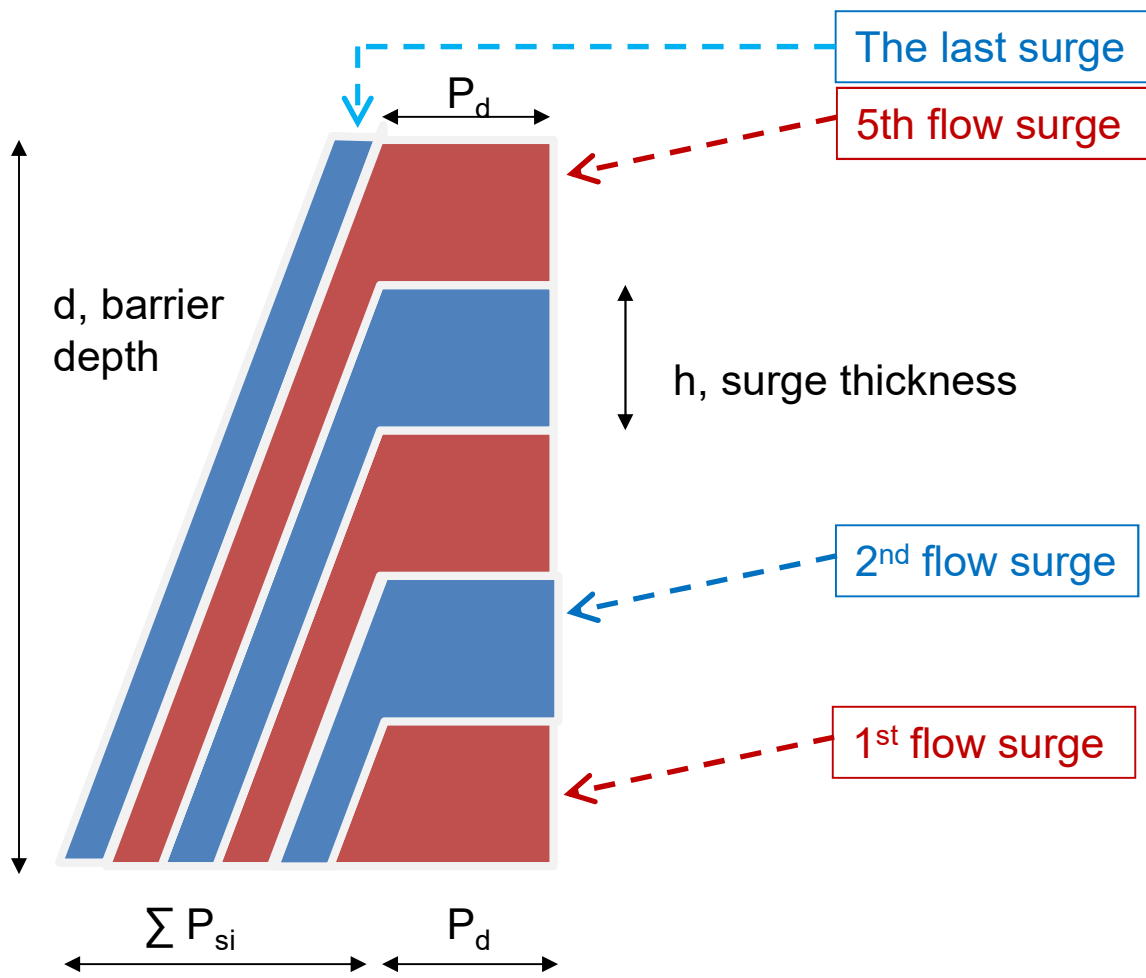
Dynamic pressure + hydrostatic pressure



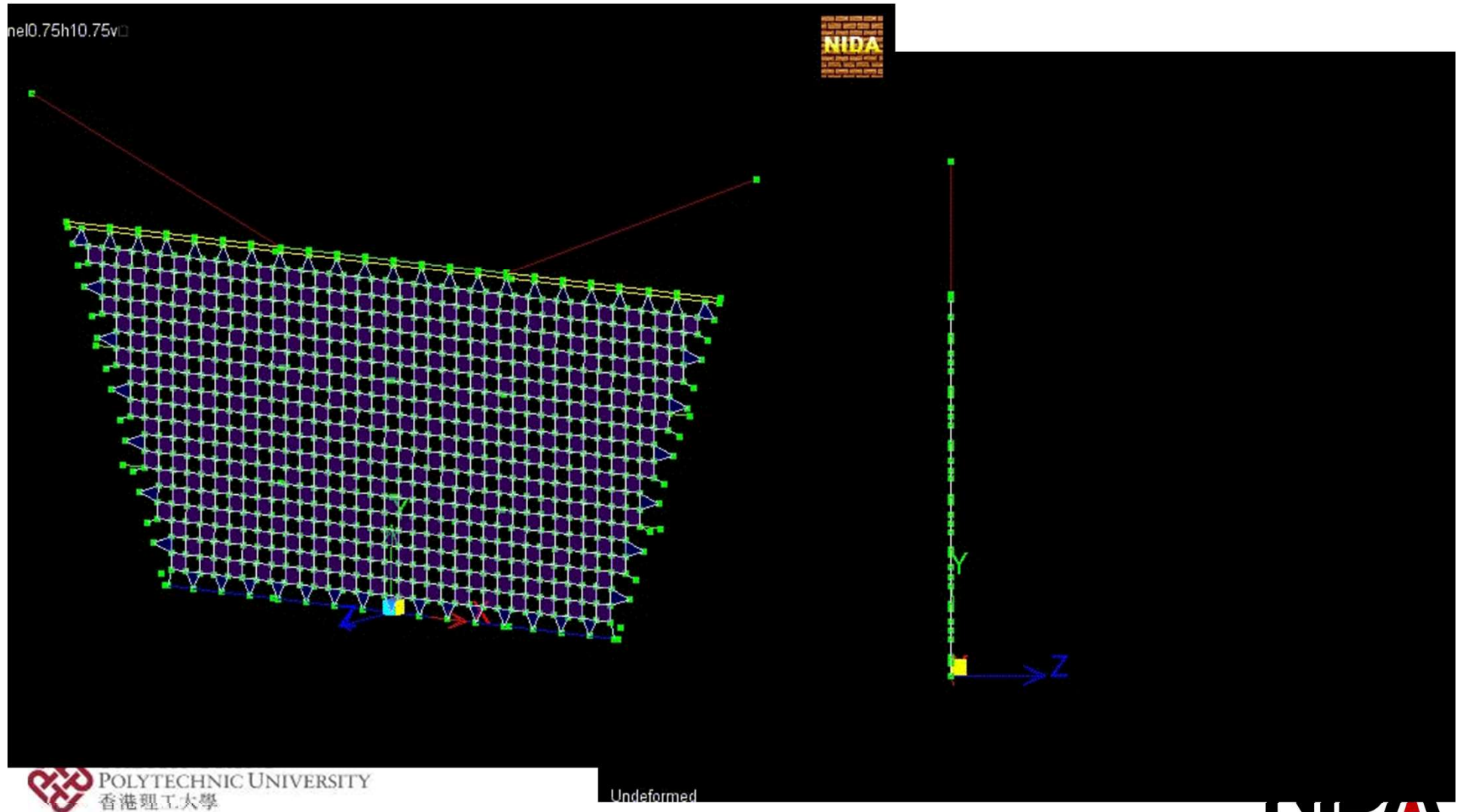
Extract from publication

Debris Flow – Force Approach

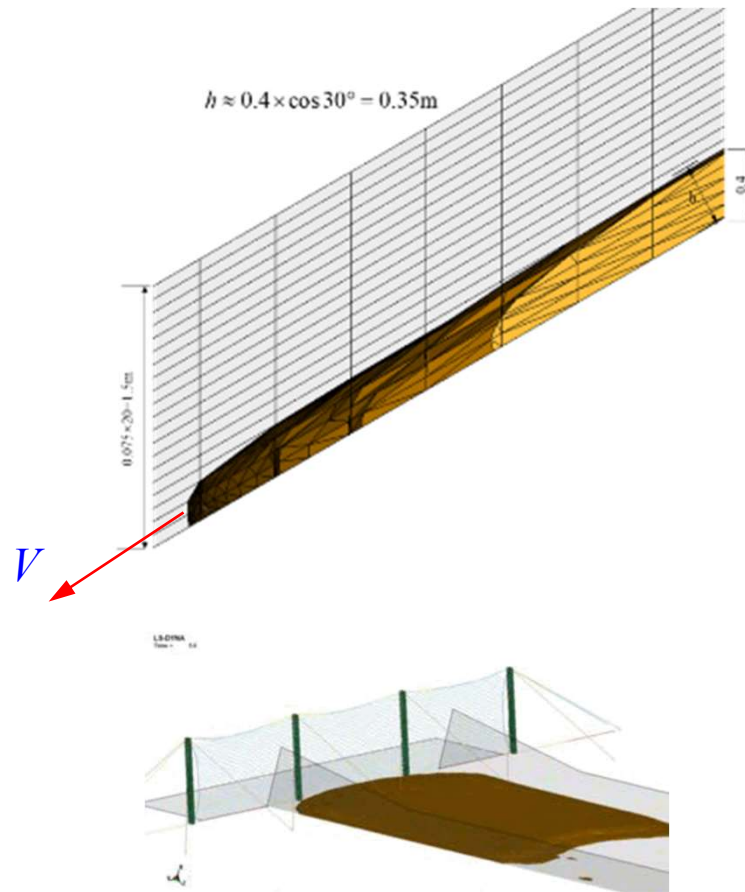
The i^{th} debris flow pressure: $P_{si} = \rho g h$, $P_d = \alpha \rho v^2$ (kN/ m²)



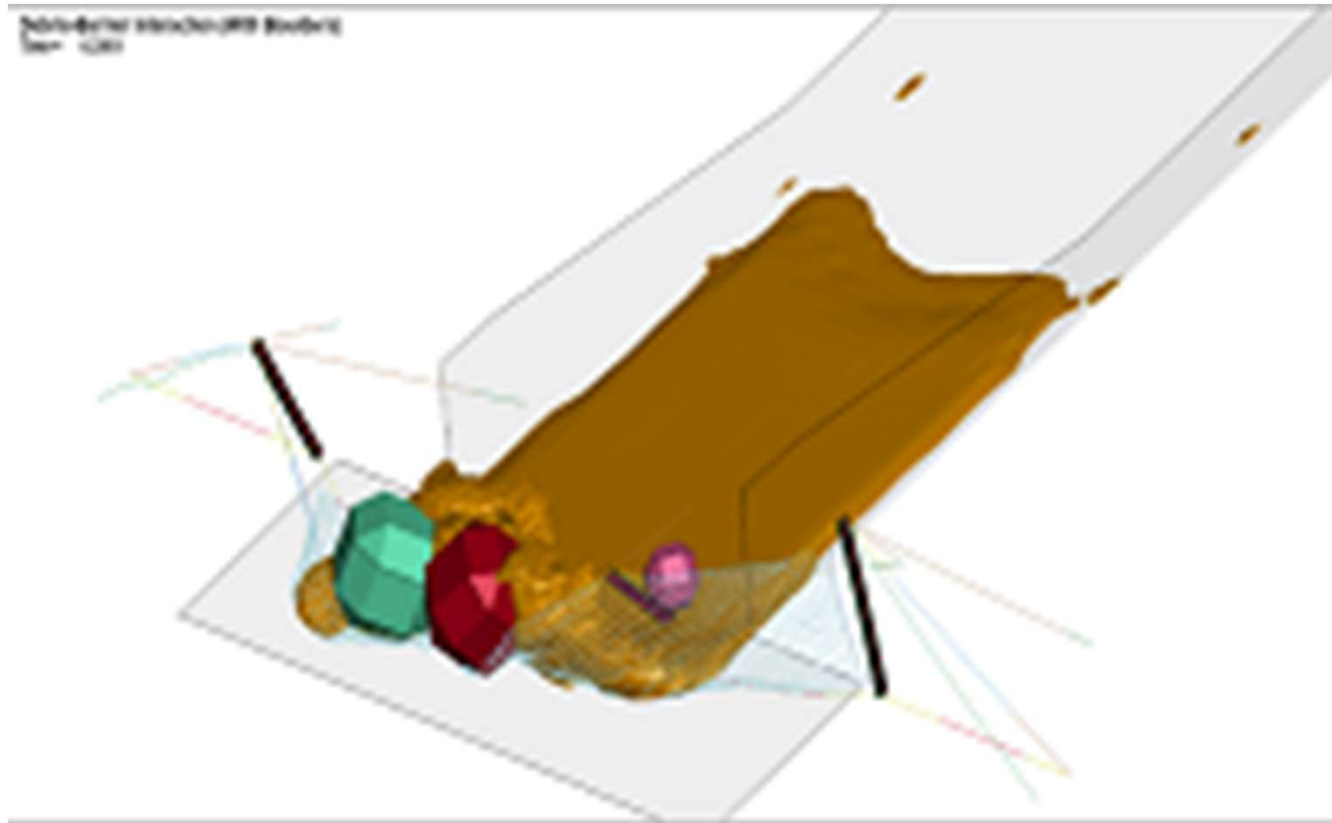
Debris Flow – Force Approach



Mobility Analysis of Debris Flow

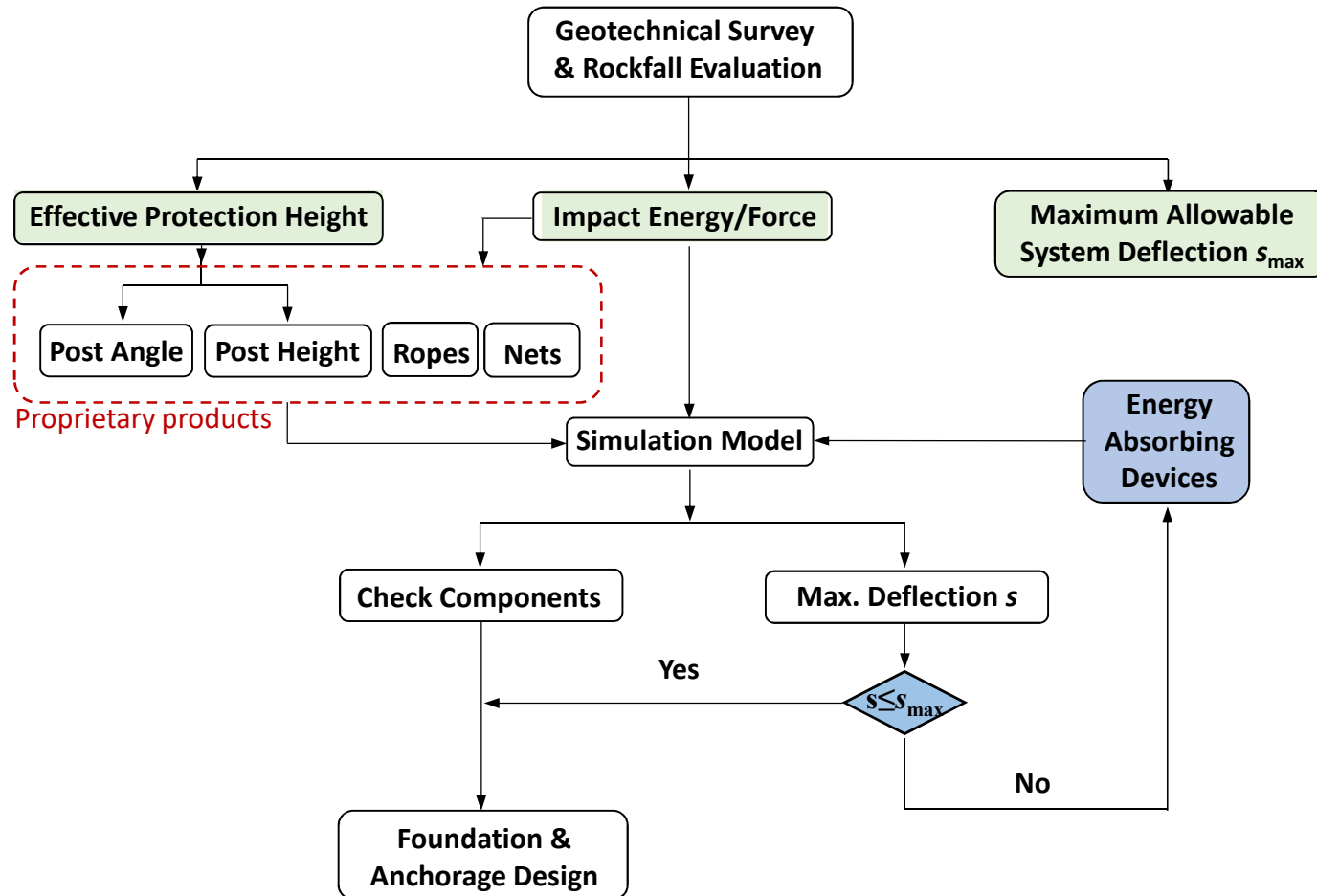


Interaction Analysis of Debris Flow + Boulder + Net



Ls-Dyna

Design Flowchart Using Nida-MNN



- Flexible barrier system is light yet they can absorb high energy through the large elasto-plastic deformations and sliding node action.
- NIDA-MNN is specially developed for flexible barrier system against rockfall and debris flow.
- NIDA-MNN is a robust and simple software for modelling of flexible barrier system against rockfall and debris flow.
- Flexible barrier system can be designed and fabricated in Hong Kong.



THANK YOU

www.nidacse.com



Workshop on Numerical Modelling for Design of Flexible Debris-resisting Barriers



Organized by
Geotechnical Division, Hong Kong Institution of Engineers

Supported by
Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University

Hands-on Exercises of NIDA-MNN

- Part 1: Modeling of Steel Frames

Prof. SL Chan, Dr. ZH Zhou, Dr. YP Liu
Mr. JW He and Dr. L Zhao

16th April, 2019

The Hong Kong Polytechnic University

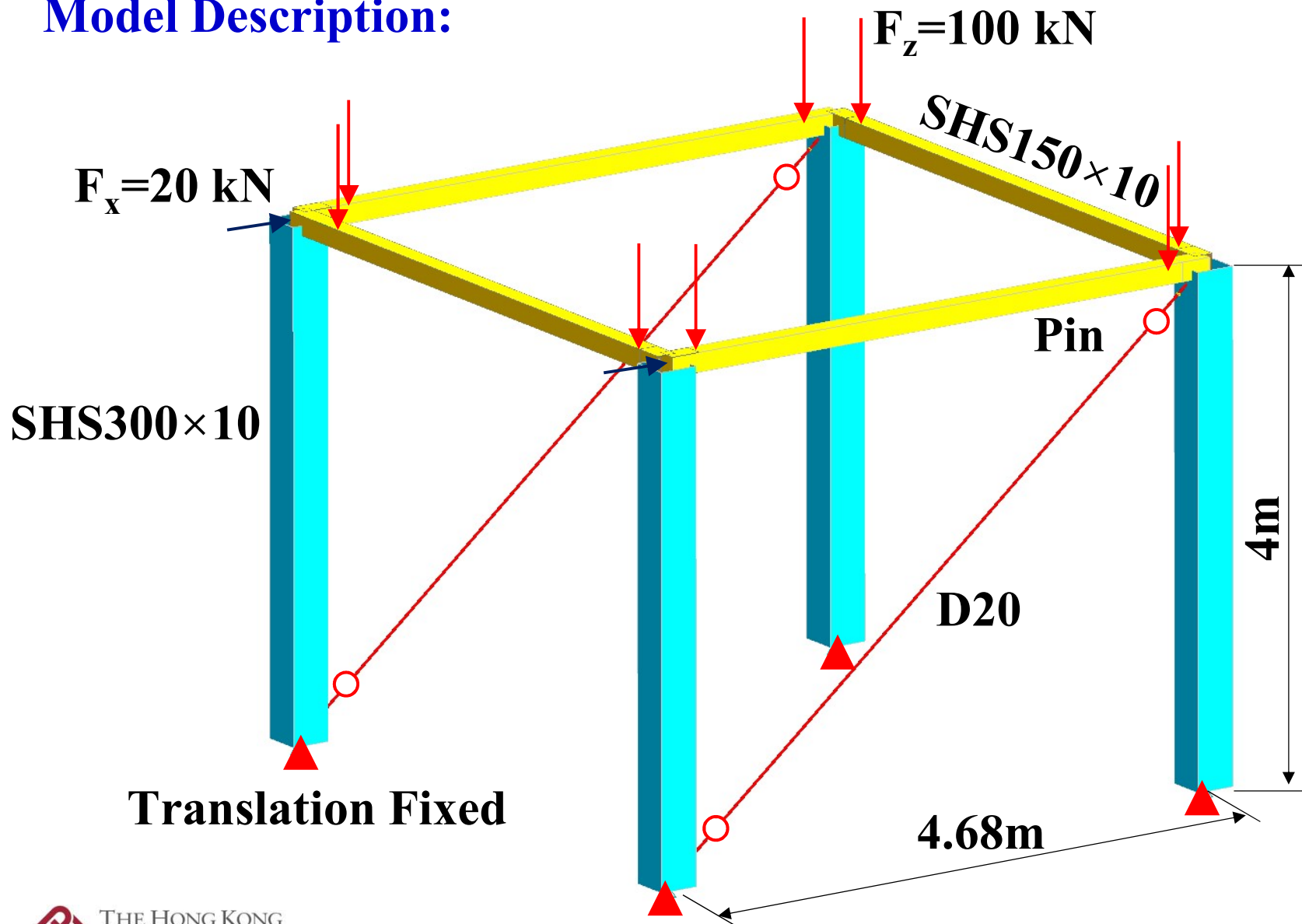


Nida-MNN – A product of Nida family (*BD Reference: S0884*)

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- NIDA-MNN provides an unified and user-friendly interface to assist the engineers to design a flexible barrier system like conventional steel structures.
- Unlike the commercial FE software using solid element to simulate flexible barrier, NIDA-MNN uses advanced beam-column element which leads to significant saving of modelling and computational time.

1 Modeling of Steel Frames

Model Description:



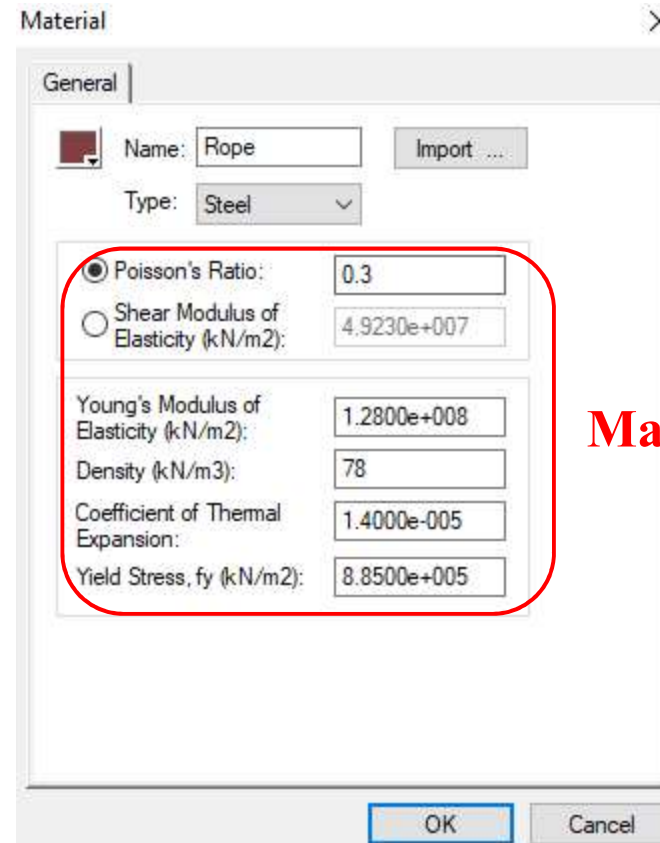
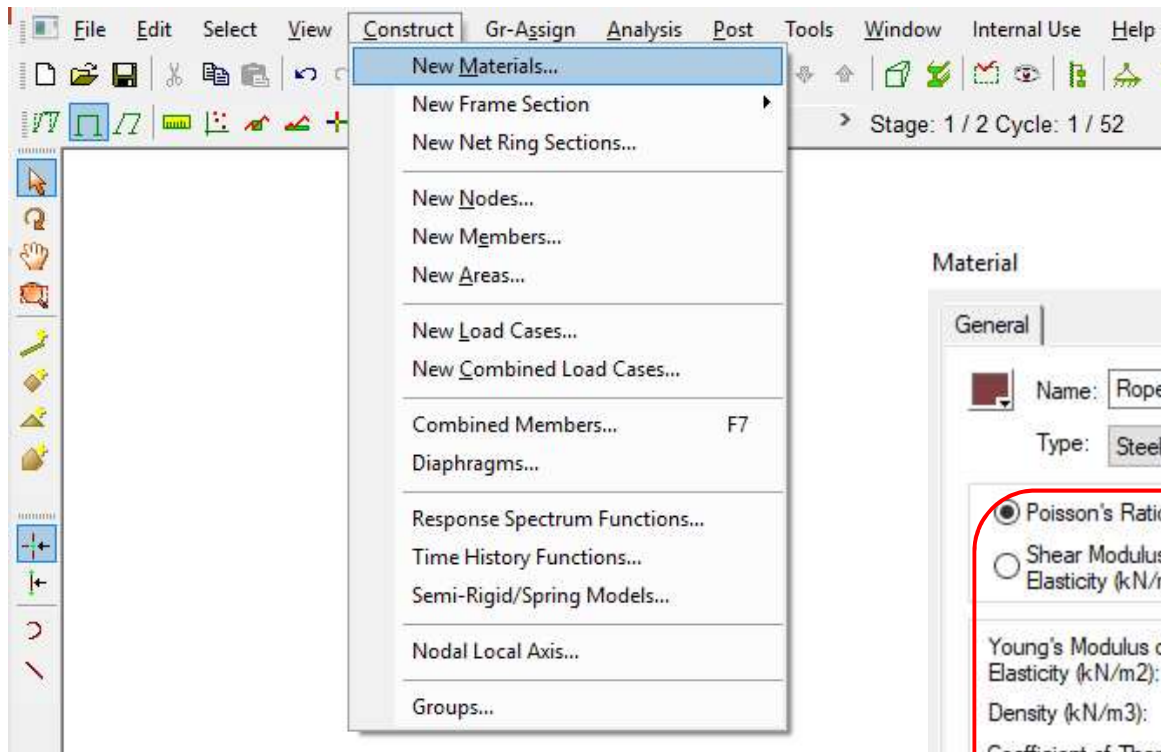
Add Material & Section

Add Material-S355

The image shows a software interface with the 'Construct' menu open, highlighting 'New Materials...'. The 'Material' dialog box is open, showing 'Name: S355' and 'Type: Steel'. The 'Material Table' dialog box is also open, showing 'Type: Steel', 'Standard: BS EN', and 'Grade: S355'. Red boxes highlight the 'Import ...' button in the 'Material' dialog and the 'Standard' and 'Grade' dropdowns in the 'Material Table' dialog.

Property	Value
Name	S355
Type	Steel
Poisson's Ratio	0.3
Shear Modulus of Elasticity (kN/m ²)	7.8846e+007
Young's Modulus of Elasticity (kN/m ²)	2.0500e+008
Density (kN/m ³)	77
Coefficient of Thermal Expansion	1.4000e-005
Yield Stress, fy (kN/m ²)	3.5500e+005

Add Material-Rope



6 Analysis & Design of Flexible Barriers

Add Frame Section-SHS300×10 (Column)

The screenshot shows the 'New Frame Section' dialog box in a software application. The 'Material' dropdown is set to 'S355' and the 'Type' is '3. Box[RHS/SHS/...]'. The 'Import ...' button is highlighted with a red box. The 'Section Properties (Analysis)' section includes fields for Cross Sectional Area (A), Shear Area Correction Factor, Second Moment of Area (Iy), Second Moment of Area (Iz), and Torsional Constant (J). The 'Section Modulus (Design)' section includes fields for About y-axis (Zy), About z-axis (Zz), About y-axis (Sy), and About z-axis (Sz). The 'Stress Type' is set to 'Direct Sum of Stress'.

Section Table

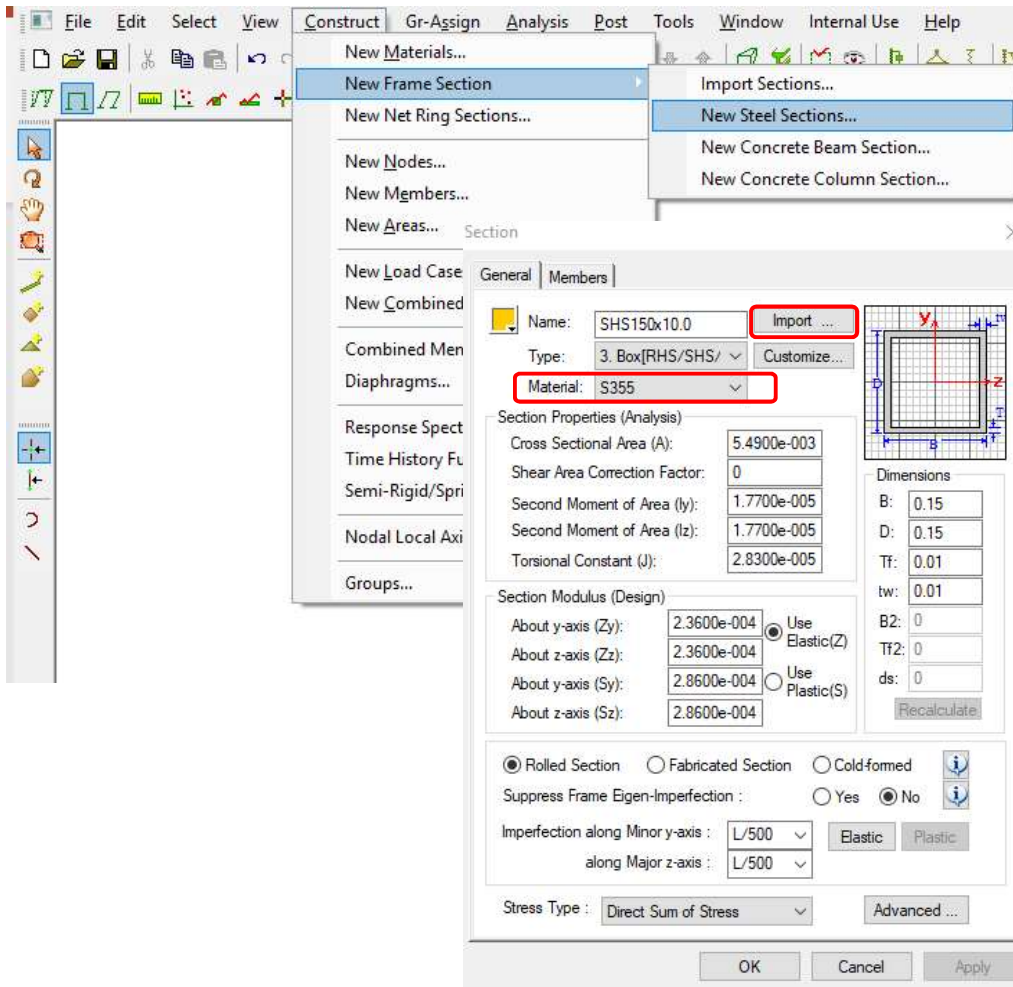
U.K. Box/Rect.

Name	B(cm)	D(cm)	Tf(cm)	tw(cm)	Area(c
SHS400x20.0~	40.00	40.00	2.00	2.00	300.00
SHS400x16.0~	40.00	40.00	1.60	1.60	243.00
SHS400x12.5	40.00	40.00	1.25	1.25	192.00
SHS400x10.0~	40.00	40.00	1.00	1.00	155.00
SHS350x16.0~	35.00	35.00	1.60	1.60	211.00
SHS350x12.5~	35.00	35.00	1.25	1.25	167.00
SHS350x10.0~	35.00	35.00	1.00	1.00	135.00
SHS350x8.0~	35.00	35.00	0.80	0.80	109.00
SHS300x16.0~	30.00	30.00	1.60	1.60	179.00
SHS300x12.5~	30.00	30.00	1.25	1.25	142.00
SHS300x10.0~	30.00	30.00	1.00	1.00	115.00
SHS300x8.0~	30.00	30.00	0.80	0.80	92.80

OK Cancel

6 Analysis & Design of Flexible Barriers

Add Frame Section-SHS150×10 (Beam)



Section Table

U.K. Box/Rect.

Name	B(cm)	D(cm)	Tf(cm)	tw(cm)	Area(c
SHS160x10.0~	16.00	16.00	1.00	1.00	58.90
SHS160x8.0~	16.00	16.00	0.80	0.80	48.00
SHS160x6.3~	16.00	16.00	0.63	0.63	38.30
SHS160x6.0	16.00	16.00	0.60	0.60	36.80
SHS160x5.0~	16.00	16.00	0.50	0.50	30.70
SHS150x16.0~	15.00	15.00	1.60	1.60	83.00
SHS150x12.5~	15.00	15.00	1.25	1.25	67.10
SHS150x10.0	15.00	15.00	1.00	1.00	54.90
SHS150x8.0~	15.00	15.00	0.80	0.80	44.80
SHS150x6.3	15.00	15.00	0.63	0.63	35.80
SHS150x5.0~	15.00	15.00	0.50	0.50	28.70
SHS140x12.5~	14.00	14.00	1.25	1.25	62.10

OK Cancel

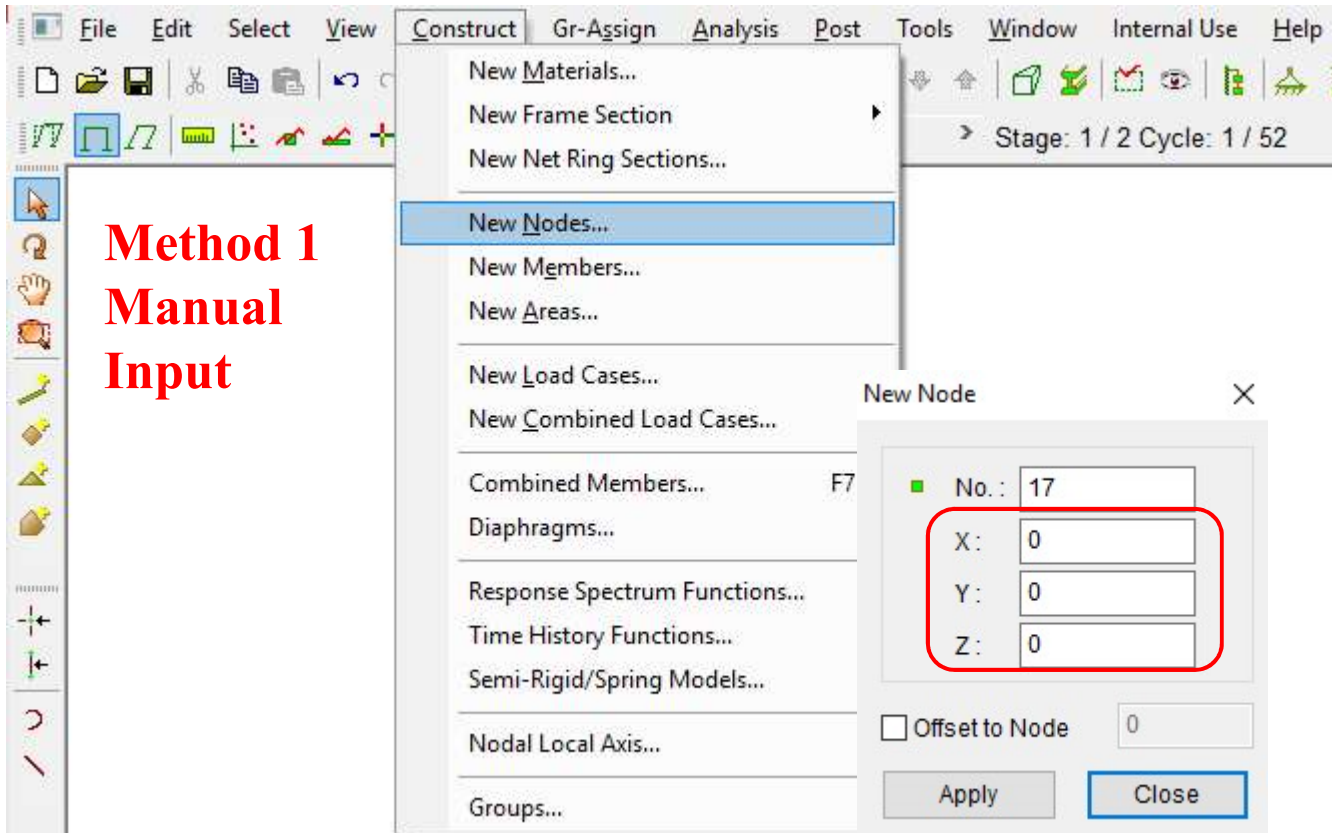
6 Analysis & Design of Flexible Barriers

Add Frame Section-D22 (Cable)

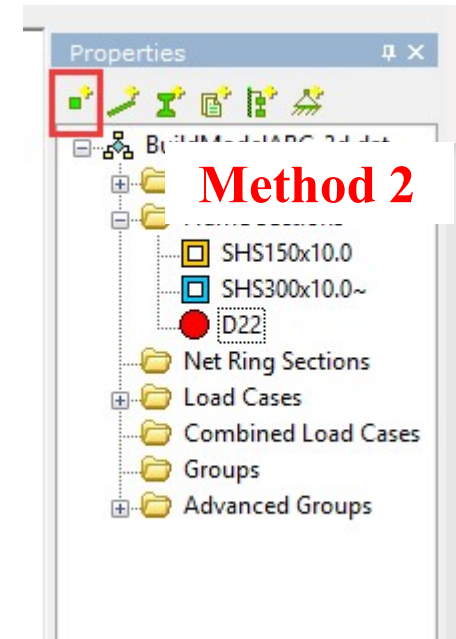
The screenshot shows the 'Section' dialog box in a software application. The 'General' tab is active. The 'Name' is 'D22'. The 'Type' is '2. Solid Bar' and the 'Material' is 'Rope'. The 'Section Properties (Analysis)' section includes: Cross Sectional Area (A): 3.8013e-004, Shear Area Correction Factor: 0, Second Moment of Area (Iy): 1.1499e-008, Second Moment of Area (Iz): 1.1499e-008, and Torsional Constant (J): 2.2998e-008. The 'Section Modulus (Design)' section includes: About y-axis (Zy): 1.0454e-006, About z-axis (Zz): 1.0454e-006, About y-axis (Sy): 1.7729e-006, and About z-axis (Sz): 1.7729e-006. The 'Dimensions' section shows: B: 0.022, D: 0, Tf: 0, tw: 0, B2: 0, Tf2: 0, and ds: 0. The 'Stress Type' is set to 'Tension Only'. A red box highlights the 'B: 0.022' field with the text 'Manual Input' next to it.

Add Node & Element & Boundary

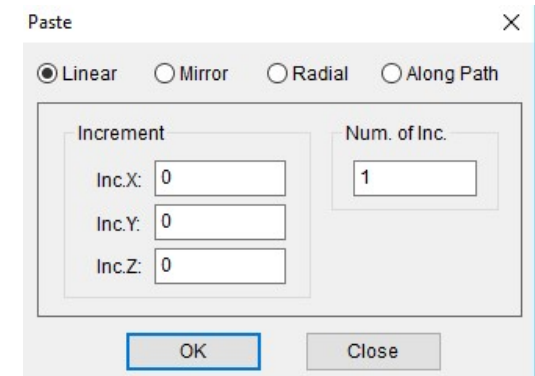
Add Node



**Method 1
Manual
Input**



**Method 3:
Copy & Paste**



Add Member

The screenshot illustrates three methods for adding a member in a structural analysis software:

- Method 1:** Accessing the 'New Members...' option from the 'Construct' menu.
- Method 2:** Selecting a member icon in the 'Properties' tree on the right, which is associated with the model 'BuildModelABC-3d.dat'.
- Method 3:** Clicking the member icon in the software's toolbar.

The 'New Member' dialog box is shown with the following details:

- Section: SHS150x10.0
- Length: 0.000
- Weight: 0.000
- Orientation Angle (Local Axis): 0
- Node 2: No.: 0, X: 0, Y: 0, Z: 0

The 'Member Properties' dialog box shows:

- Section: SHS300x10.0~
- End Condition: Both Rigid

The 'Properties' tree on the right lists various model components, including 'SHS150x10.0' and 'SHS300x10.0~'.

Add Boundary Condition

Method 1

Method 2

Select Nodes First

Assign Node Properties

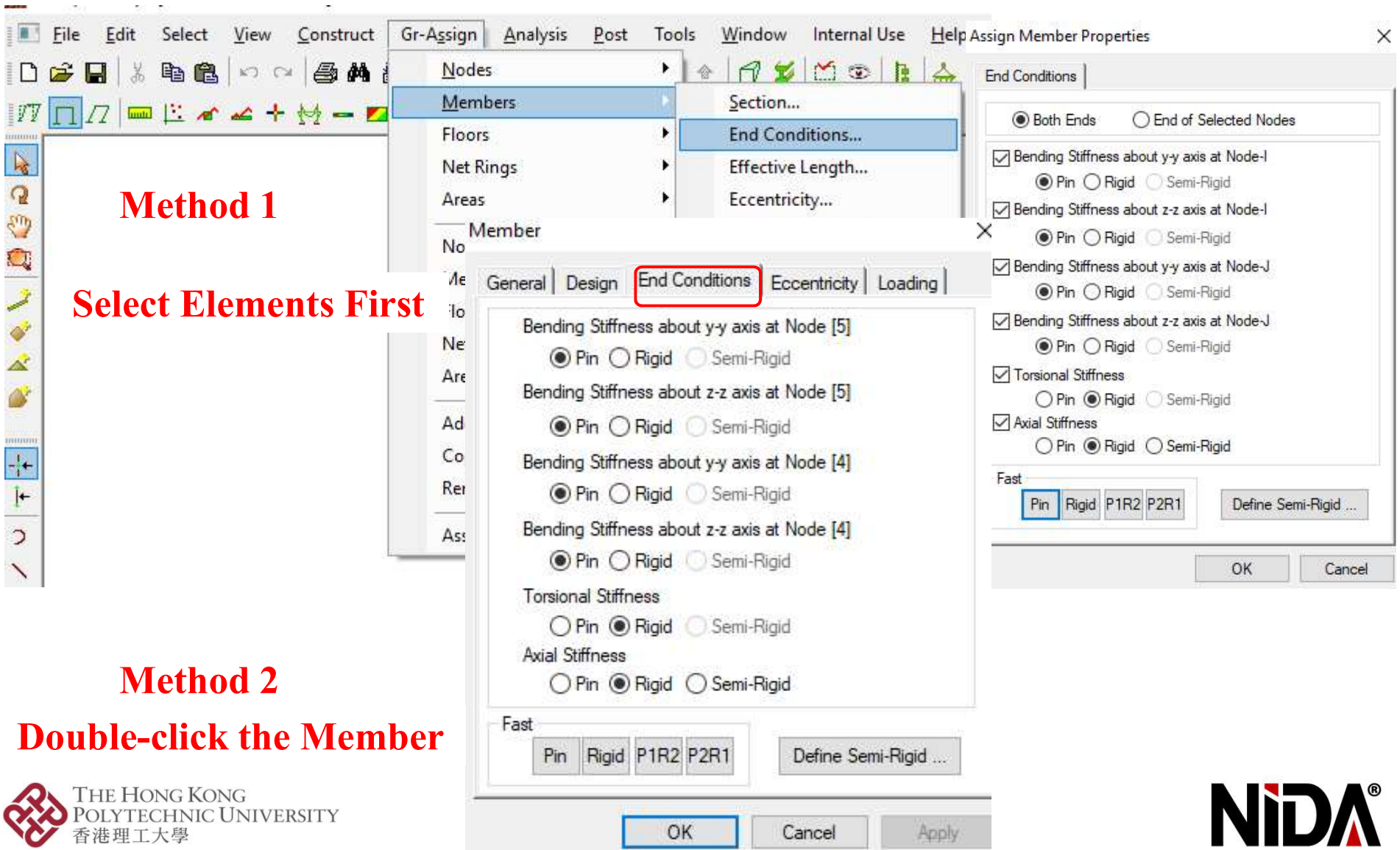
Property	Free	Restraint
Displacement: UX	<input type="radio"/>	<input checked="" type="radio"/>
UY	<input type="radio"/>	<input checked="" type="radio"/>
UZ	<input type="radio"/>	<input checked="" type="radio"/>
Rotation: RX	<input checked="" type="radio"/>	<input type="radio"/>
RY	<input checked="" type="radio"/>	<input type="radio"/>
RZ	<input checked="" type="radio"/>	<input type="radio"/>

Fast Restraints:

OK Cancel Apply

Set Member End Conditions

Method 1
Select Elements First



The screenshot shows the software interface with the 'Members' menu open, highlighting 'End Conditions...'. The 'Assign Member Properties' dialog box is open, with the 'End Conditions' tab selected. The 'End Conditions' section is highlighted with a red box. The 'Fast' section shows 'Pin' selected.

Method 2
Double-click the Member

Add Load

Add Load Case

The image displays the NIDA software interface with two methods for adding a load case:

- Method 1:** The 'Construct' menu is open, and 'New Load Cases...' is highlighted.
- Method 2:** The 'Properties' tree on the right shows the 'Load Cases' folder expanded, with 'LL(1.00)' selected.

The 'Load Case' dialog box is open, showing the following settings:

- Name: LL
- Type: Live Load (highlighted with a red box)
- No.: 2
- Factor: 1.0
- Auto Self Weight (highlighted with a red box)
- Show Loadings on Structure
- Show Values

Buttons at the bottom of the dialog include OK, Cancel, and Apply.

Add Load

Method 1

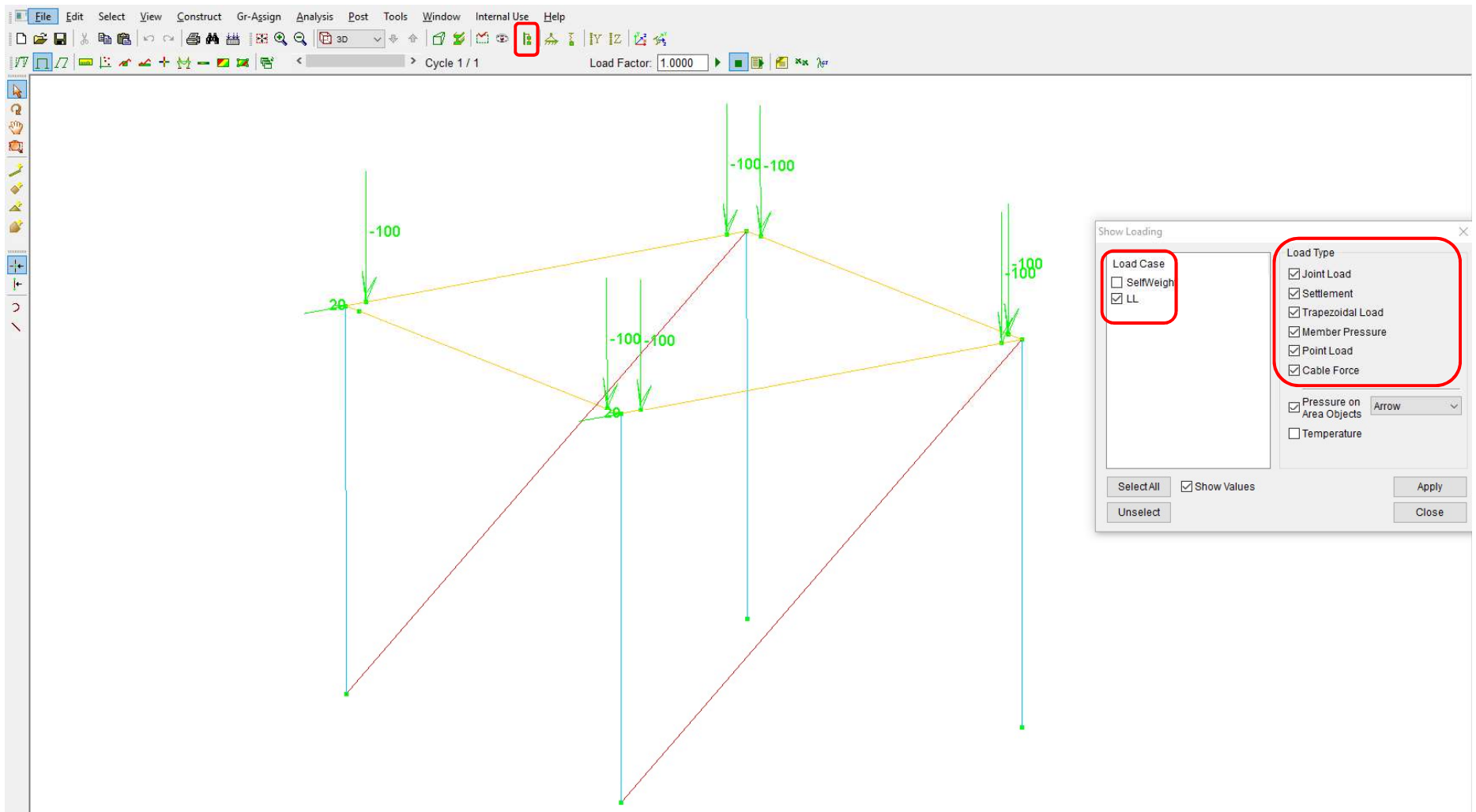
Method 2

Select Nodes First

The screenshot displays the software's main window with the 'Gr-Assign' menu open. Under 'Nodal Loads', 'Joint Loads...' is selected. The 'Loading Properties' dialog is open, showing 'Load Case: LL' and 'Load Type: Joint Load' highlighted with red boxes. The dialog also includes input fields for Force (FX, FY, FZ) and Moment (MX, MY, MZ), all set to 0, and an 'Axis' section with 'Global' selected. The 'Properties' tree on the right shows a project named 'BuildModelABC-3d.dat' with various sections like Materials, Frame Sections, and Load Cases. The 'Load Cases' folder contains 'SelfWeight(1.00)' and 'LL(1.00)'. The 'Apply' and 'Close' buttons are visible at the bottom of the dialog.

6 Analysis & Design of Flexible Barriers

Show Loading



Set Analysis Case

Analysis Case

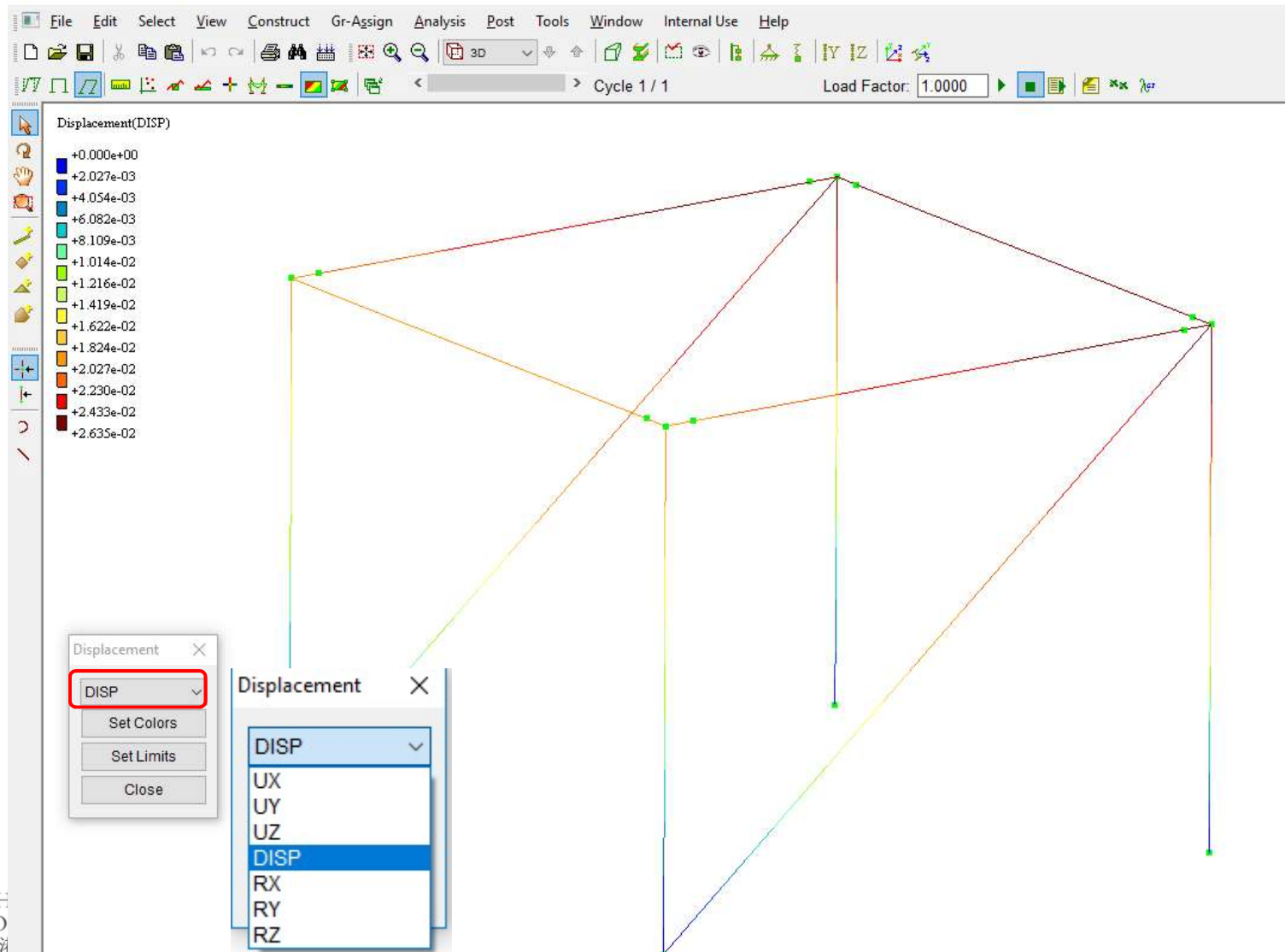
The screenshot displays the software interface for setting up an analysis case. The 'Analysis Cases' window shows a table with one entry: 'NONLINEAR: DL + LL' with ID 1. The 'NONLINEAR: DL + LL' dialog box is open, showing the 'Second-Order Analysis' tab. The 'Name' field is 'NONLINEAR: DL + LL' and the 'Type' is 'Second-order Analysis + Design'. The 'PEP Element' radio button is selected. The 'Applied Loads' tab is also visible, showing 'General Load Cases' set to 'Load Case' and a table of 'Loads Applied'.

Name	Type	Factor
SelfWeight	Load Case	1.40
LL	Load Case	1.60

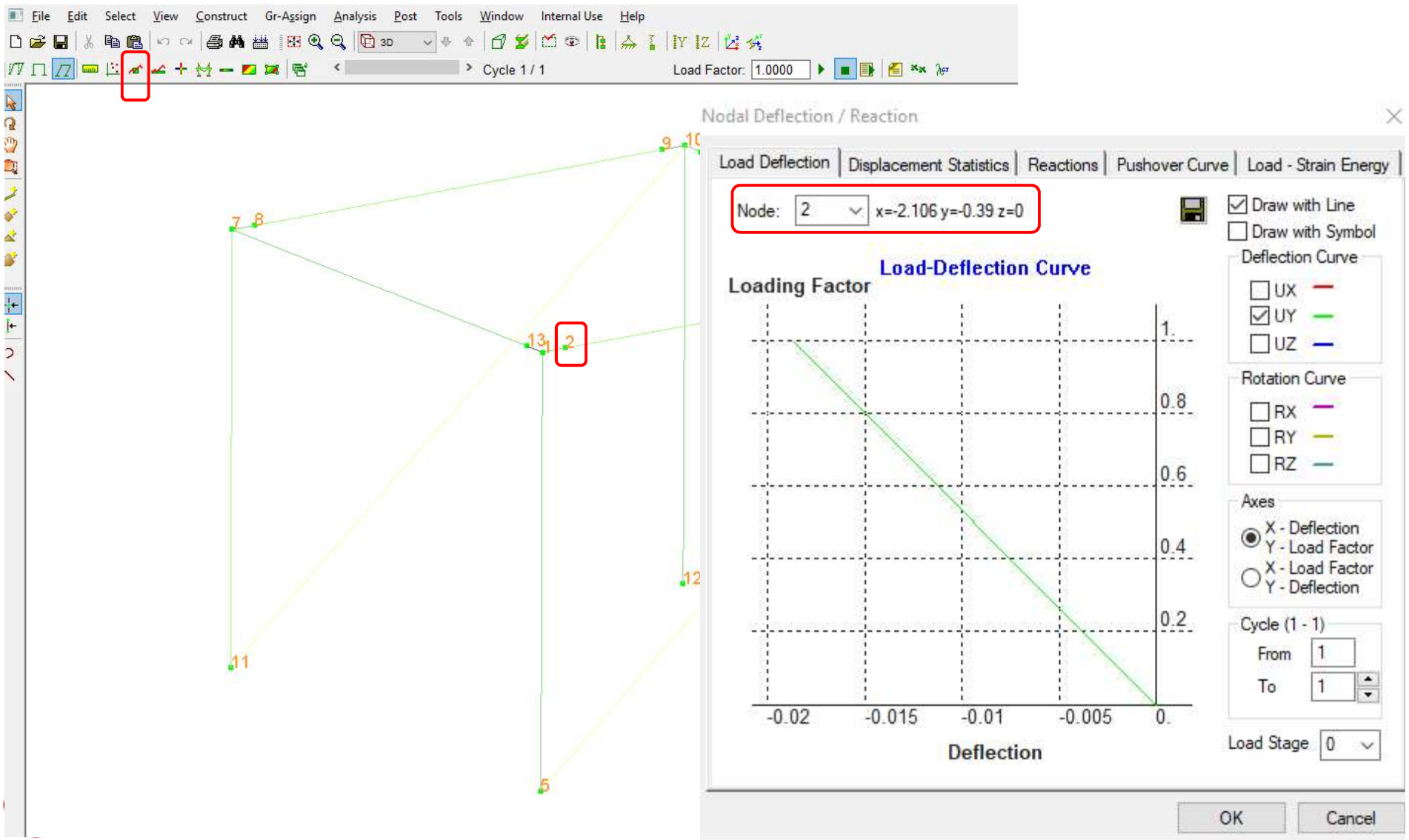
The 'Edit' menu is open, highlighting 'Nonlinear Analysis'.

Post

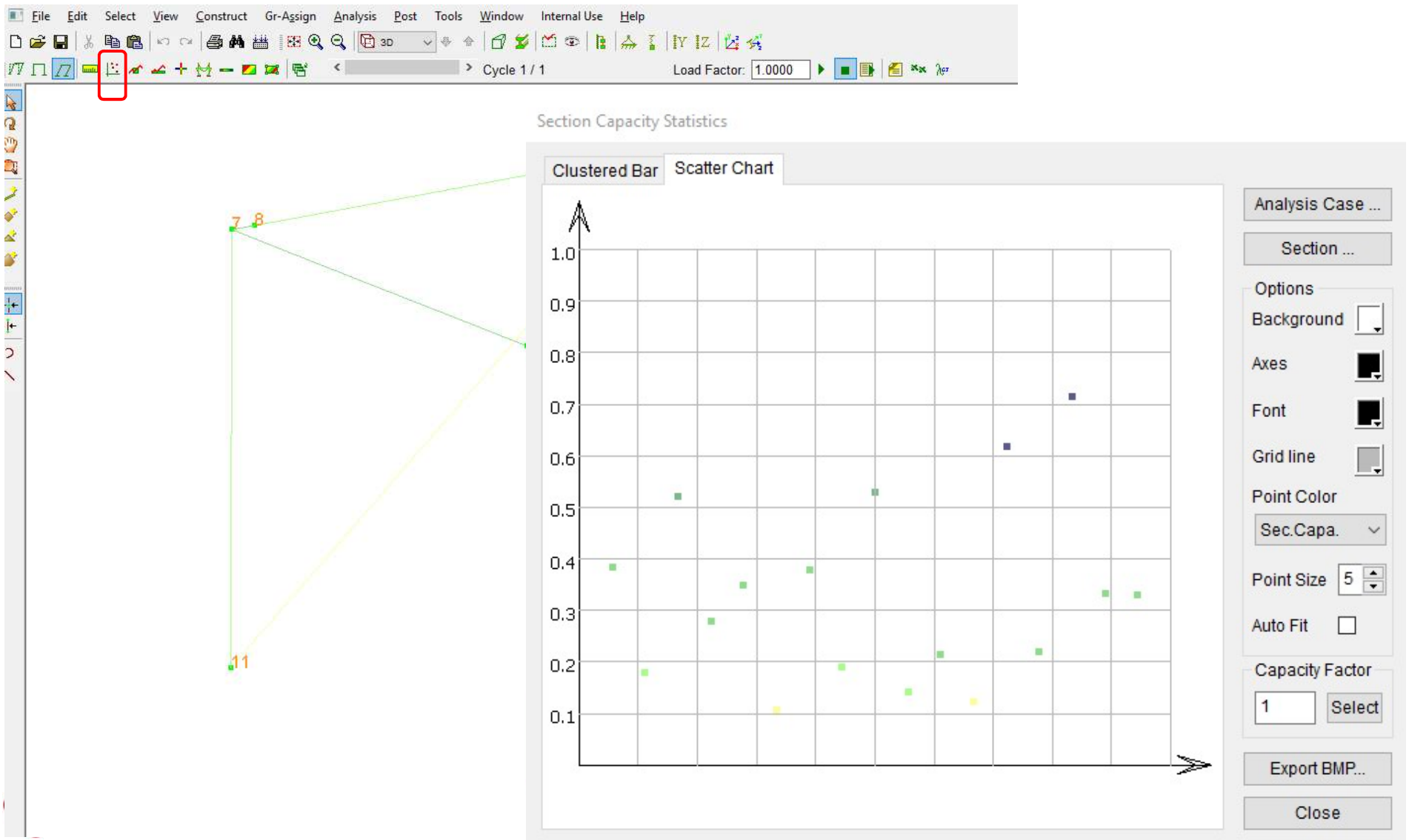
Nodal Displacement Contour



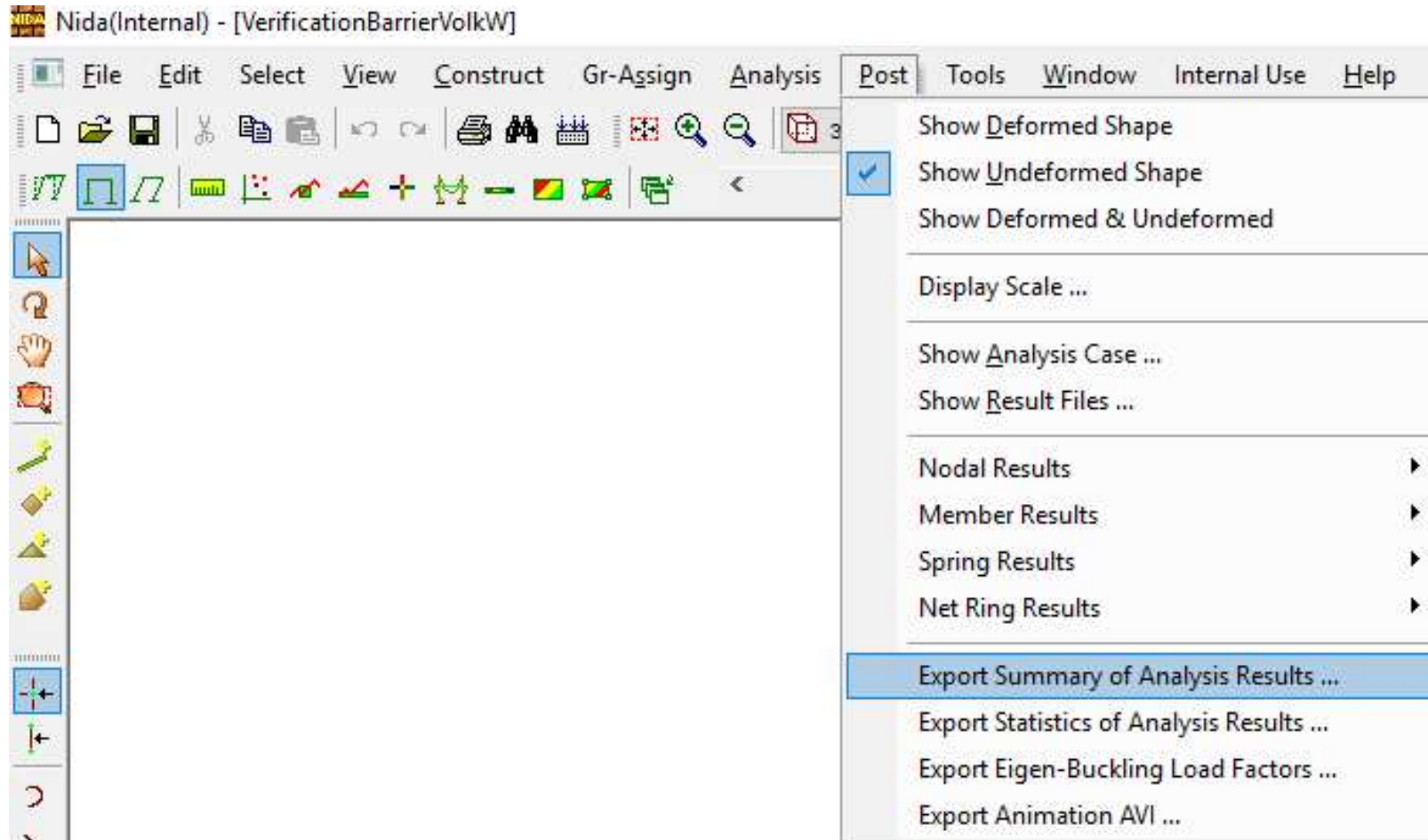
Nodal Deflection



Section Capacity Statistics



Others





THANK YOU

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Workshop on Numerical Modelling for Design of Flexible Debris-resisting Barriers



Organized by
Geotechnical Division, Hong Kong Institution of Engineers

Supported by
Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University

Hands-on Exercises of NIDA-MNN

- Part 2: Modeling of Cable Net

Prof. SL Chan, Dr. ZH Zhou, Dr. YP Liu
Mr. JW He and Dr. L Zhao

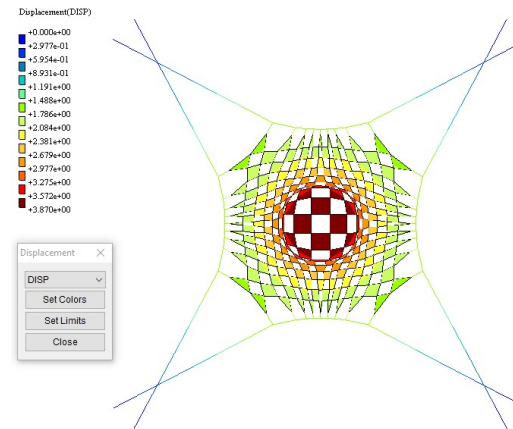
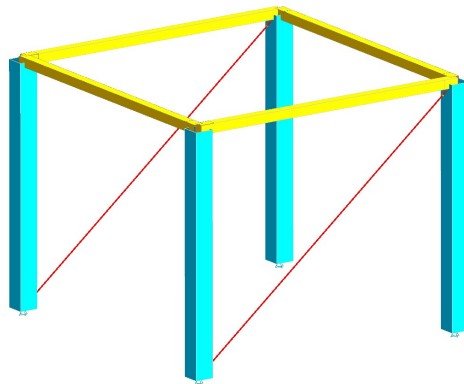
16th April, 2019

The Hong Kong Polytechnic University



Example Detailing

- Basic Operation of NIDA-MNN
- NIDA-MNN Modelling of Cable Net



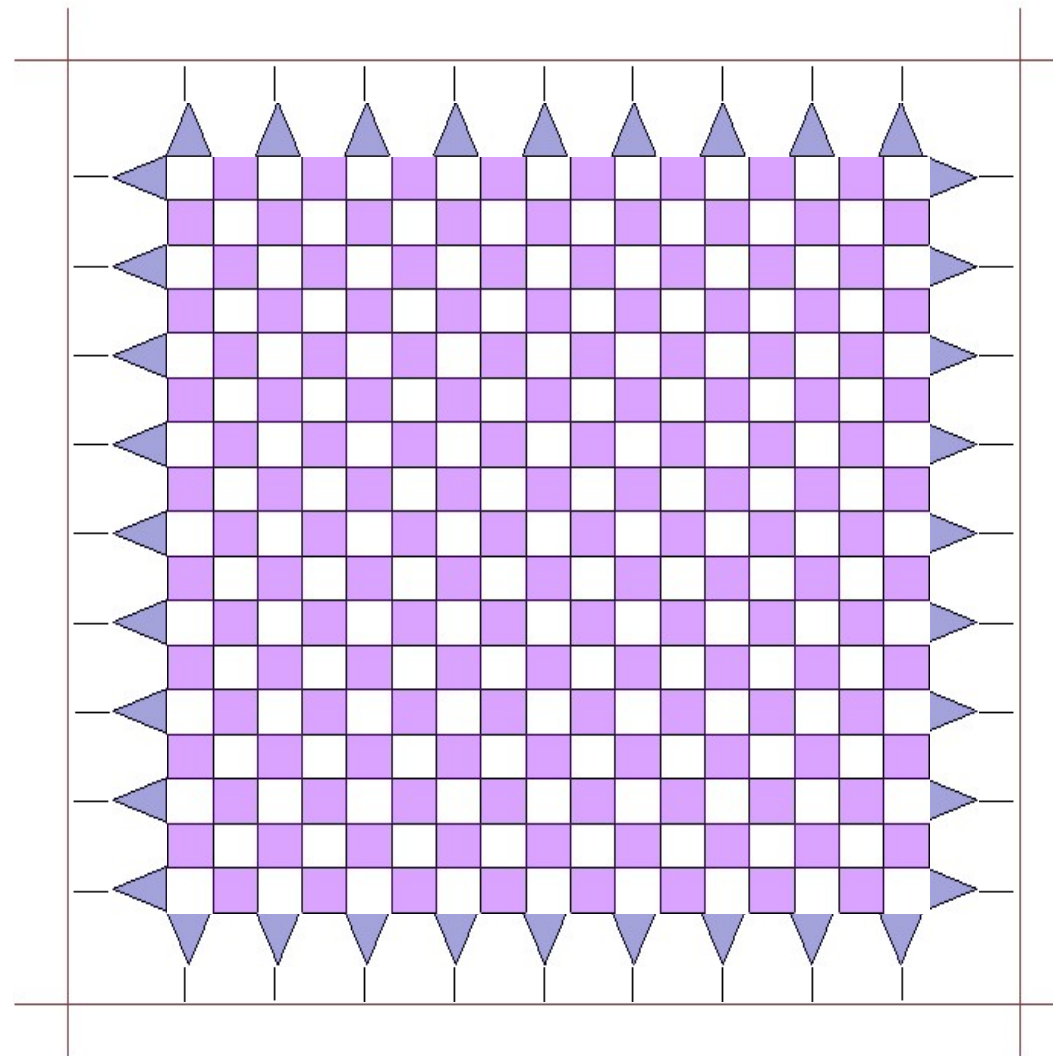
6 Analysis & Design of Flexible Barriers

3



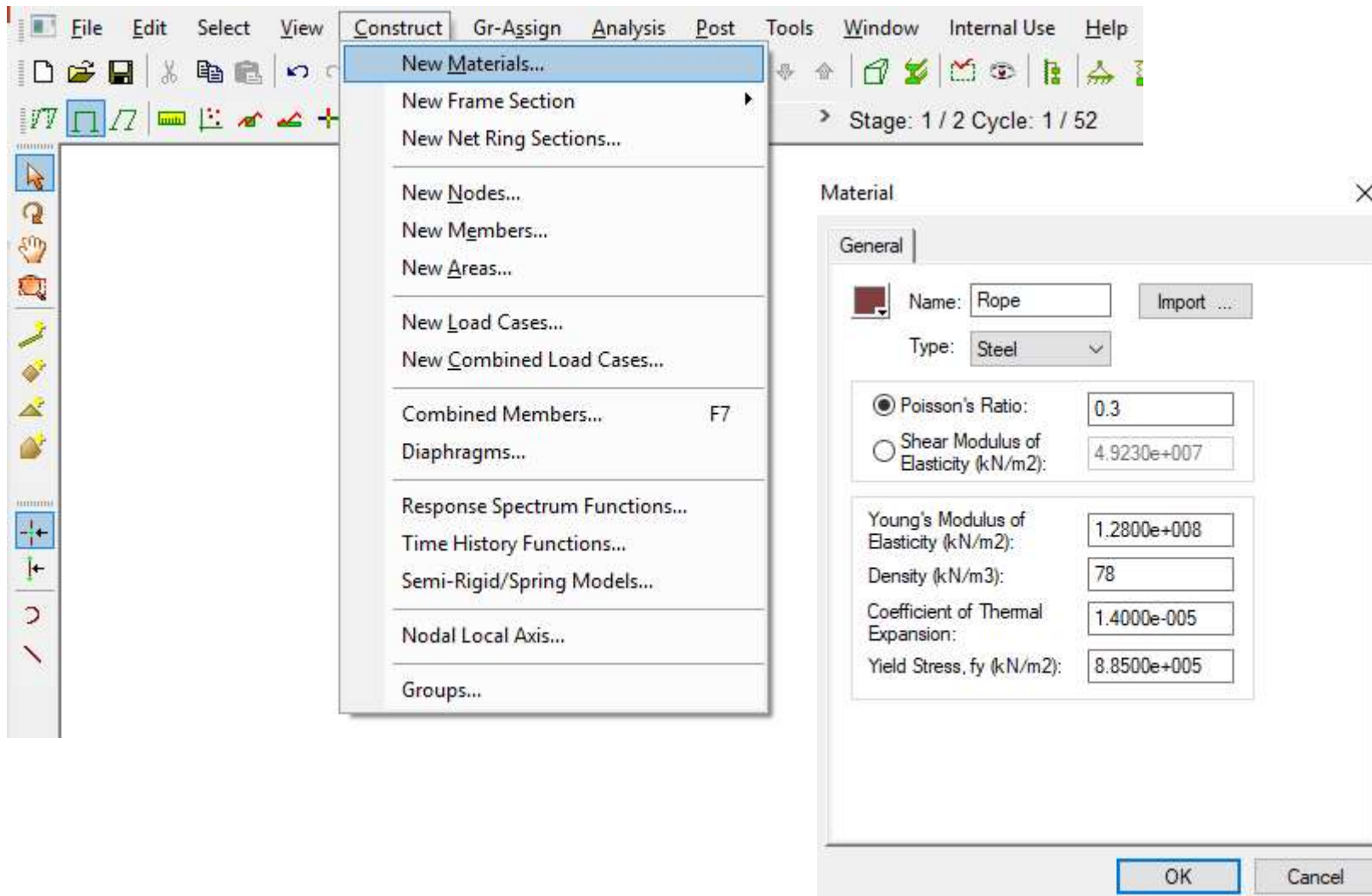
General Description of the model

Model
=
Ropes
+
Centre net
(four-point loading)
+
Side net
(three-point loading)
+
Shackles



**Add Material, Section, Node,
Element, Boundary**

Add Material



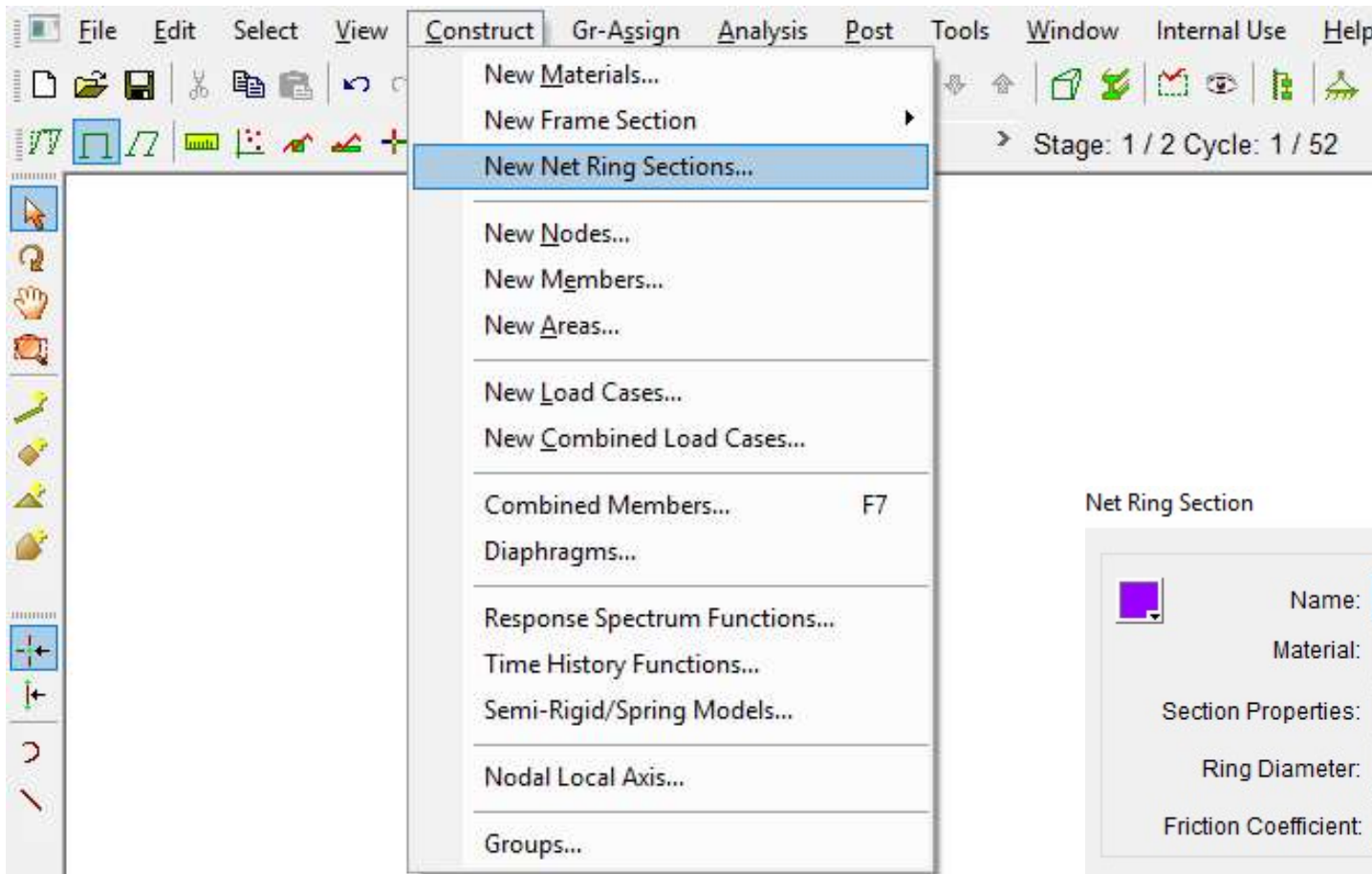
Add Frame Section

The image shows a software interface with a menu and a dialog box. The menu is open to 'New Frame Section', which has a sub-menu with 'New Steel Sections...' selected. The dialog box is titled 'Wingle Ropes 2D22' and has several tabs: 'General' and 'Members'. The 'General' tab is active. It contains the following fields:

- Name: Wingle Ropes 2D22
- Type: 2. Solid Bar
- Material: Rope
- Section Properties (Analysis):
 - Cross Sectional Area (A): 5.1200e-004
 - Shear Area Correction Factor: 0
 - Second Moment of Area (Iy): 5.6000e-011
 - Second Moment of Area (Iz): 5.6000e-011
 - Torsional Constant (J): 1.1200e-010
- Section Modulus (Design):
 - About y-axis (Zy): 5.7260e-007
 - About z-axis (Zz): 5.7260e-007
 - About y-axis (Sy): 9.7110e-007
 - About z-axis (Sz): 9.7110e-007
- Dimensions:
 - B: 0.044
 - D: 0
 - Tf: 0
 - tw: 0
 - B2: 0
 - Tf2: 0
 - ds: 0
- Stress Type: Tension Only

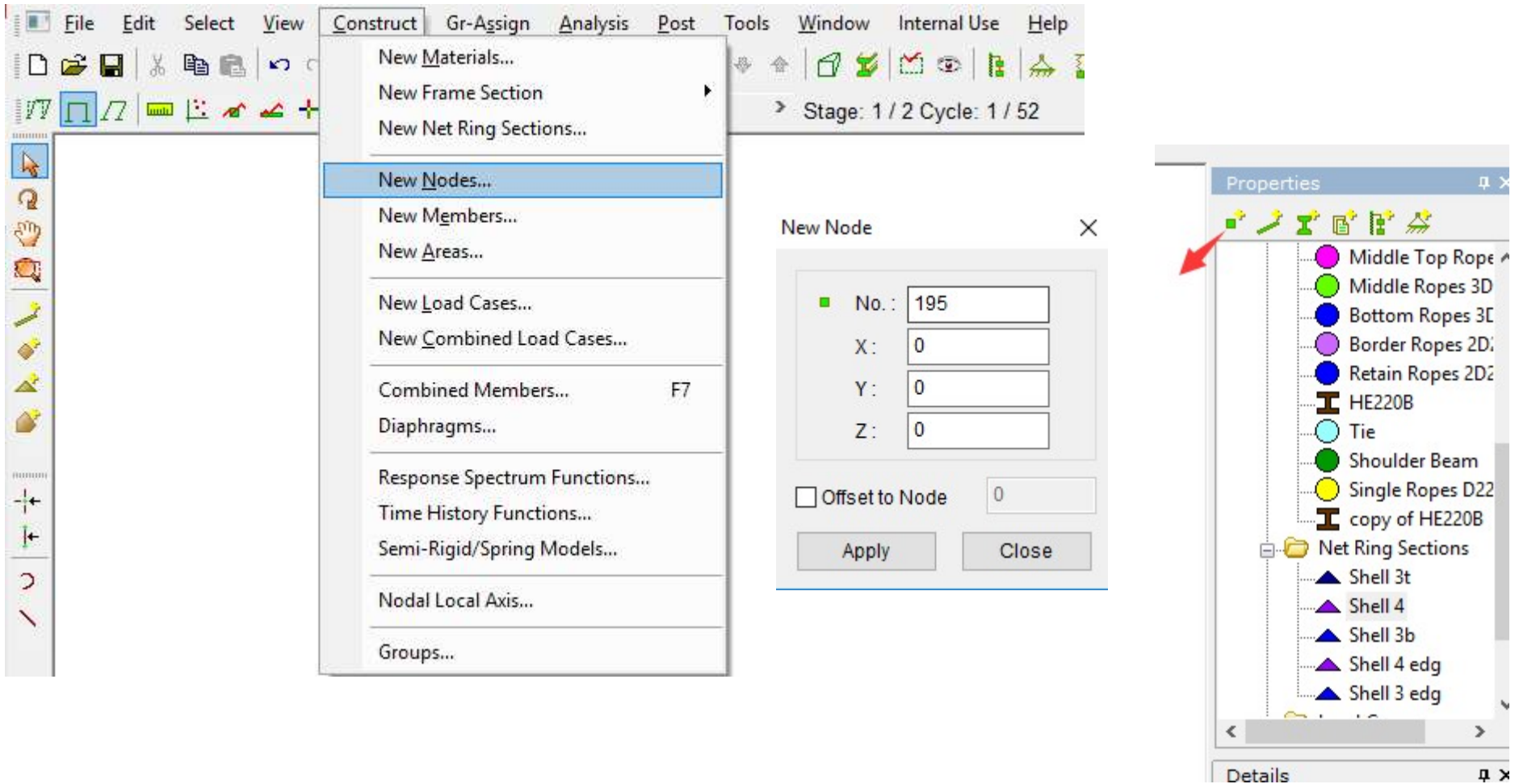
Other options in the dialog include 'Rolled Section' (selected), 'Fabricated Section', 'Cold-formed', 'Suppress Frame Eigen-Imperfection' (No), and 'Imperfection along Minor y-axis' and 'along Major z-axis' (both 0). There are 'Elastic' and 'Plastic' buttons, and an 'Advanced...' button.

Add Net Ring Section



6 Analysis & Design of Flexible Barriers

Add Node



Add Member

The image shows a screenshot of the SAP2000 software interface. The 'Construct' menu is open, and 'New Members...' is selected. The 'New Member' dialog box is displayed, showing the following settings:

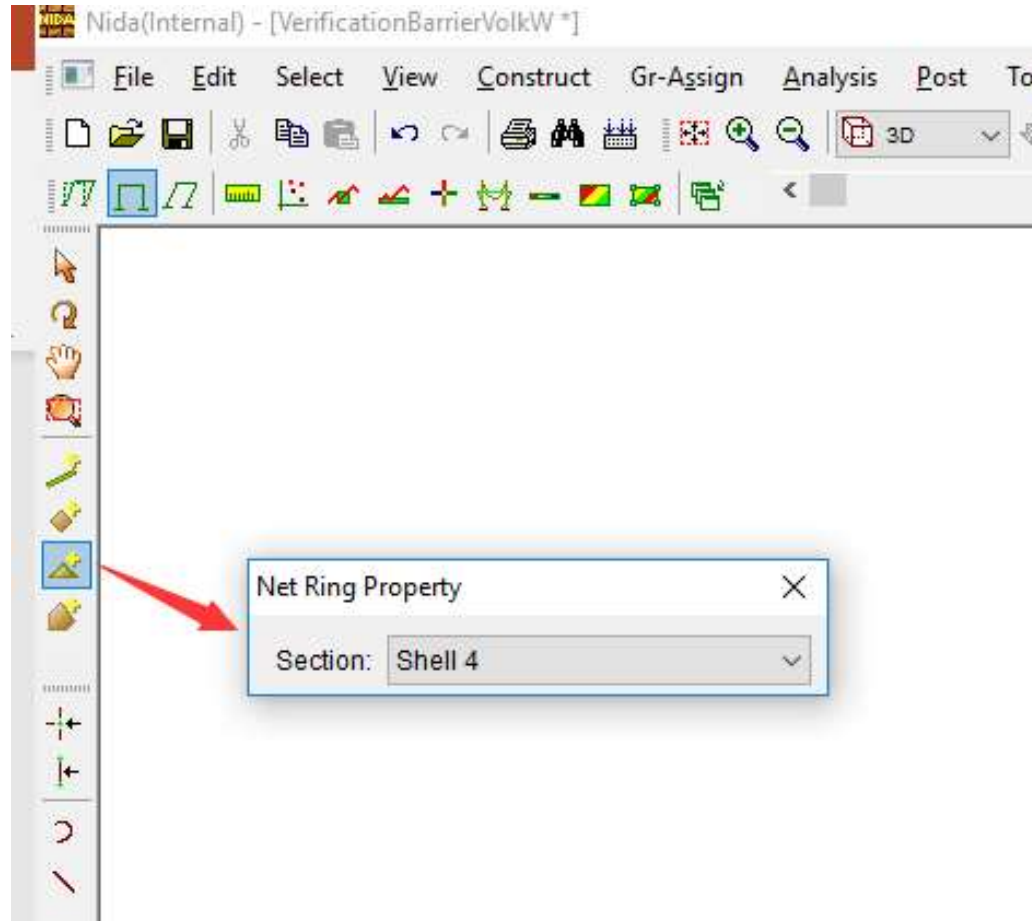
- No.: 77
- Section: Wingle Ropes 2D22
- Length: 0.000
- Weight: 0.000
- Orientation Angle (Local Axis):
 - In Degrees: 0
 - K-Node: -1
- Node 1: No.: 0, X: 0, Y: 0, Z: 0
- Node 2: No.: 0, X: 0, Y: 0, Z: 0

The 'Member Properties' dialog box is also shown, with the following settings:

- Section: Wingle Ropes 2D22
- End Condition: Both Rigid

The background shows the main SAP2000 window with the 'Nida(Internal) - [VerificationBarrierVolkW *]' title bar and various toolbars.

Add Net Ring



Add Boundary Condition

The screenshot displays the Nida software interface with the following components:

- Menu Path:** Gr-Assign > Nodes > Boundary Conditions...
- Assign Node Properties Dialog:**
 - Boundary:**
 - Displacement: UX Free Restraint
 - UY Free Restraint
 - UZ Free Restraint
 - Rotation: RX Free Restraint
 - RY Free Restraint
 - RZ Free Restraint
 - Fast Restraints:** Includes icons for various restraint types.
- Properties Panel:** Lists model components such as Middle Top Rope, Middle Ropes 3D, Bottom Ropes 3D, Border Ropes 2D, Retain Ropes 2D, HE220B, Tie, Shoulder Beam, Single Ropes D22, copy of HE220B, and Net Ring Sections (Shell 3t, Shell 4, Shell 3b, Shell 4 edg, Shell 3 edg).

Some Specific Definitions

Define Brake Element

The screenshot shows the NIDA software interface with the 'Construct' menu open, highlighting 'Semi-Rigid/Spring Models...'. The 'Define Semi-Rigid/Spring Models' dialog box is open, showing 'Type: Force-Displacement' and 'Model: Multi-linear Model'. The 'List' contains: U-brake, 2U-brake, 3U-brake, 4U-brake, GN-9017, GS-8001 (highlighted), and 1.25GS-8001. The 'Force-Displacement' dialog box shows a 'Multi-linear Model' graph with Force on the y-axis (0.000 to 111.000) and Displacement on the x-axis (0.000 to 1.10). The graph shows a non-linear relationship. Below the graph, the Name is 'GS-8001' and Initial Elastic Stiffness (Ke) is '2.8e+002'. A table of parameters is shown below:

F1 d1	0 0
F2 d2	27.5 0.1
...	68 0.9
Fn dn	111 1.1

Buttons for 'Param. Def.', 'OK', and 'Cancel' are visible at the bottom of the dialog boxes.

Add Brake Element

The screenshot shows the Nida software interface with the 'Members' menu open. The 'End Conditions...' option is selected, which has opened the 'Assign Member Properties' dialog box. In the dialog, the 'End Conditions' tab is active, and the 'Axial Stiffness' option is checked and highlighted with a red box. The 'Semi-Rigid' radio button is selected, and a dropdown menu shows 'GS-8001'. The 'Define Semi-Rigid ...' button is highlighted with a purple box.

Assign Member Properties

End Conditions

Both Ends End of Selected Nodes

Bending Stiffness about y-y axis at Node-I
 Pin Rigid Semi-Rigid

Bending Stiffness about z-z axis at Node-I
 Pin Rigid Semi-Rigid

Bending Stiffness about y-y axis at Node-J
 Pin Rigid Semi-Rigid

Bending Stiffness about z-z axis at Node-J
 Pin Rigid Semi-Rigid

Torsional Stiffness
 Pin Rigid Semi-Rigid

Axial Stiffness
 Pin Rigid Semi-Rigid GS-8001

Fast
Pin Rigid P1R2 P2R1 **Define Semi-Rigid ...**

OK Cancel

Add Sliding Property Between Shackles and Rope

The screenshot displays the Nida software interface. The 'Construct' menu is open, with 'Combined Members...' selected. The 'Combined Members' dialog box is open, showing a table of member data. The 'Properties' panel on the right shows a tree view of the model's components, with 'Combined Members' highlighted. A red arrow points from the 'Properties' panel to the 'Combined Members' dialog box.

Construct Menu:

- New Materials...
- New Frame Section
- New Net Ring Sections...
- New Nodes...
- New Members...
- New Areas...
- New Load Cases...
- New Combined Load Cases...
- Combined Members... F7**
- Diaphragms...
- Response Spectrum Functions...
- Time History Functions...
- Semi-Rigid/Spring Models...
- Nodal Local Axis...
- Groups...

Combined Members Dialog:

No.	Start No...	End No...	No. of M...
1	191	192	10
2	189	190	10
3	194	193	10
4	187	188	10

Properties Panel:

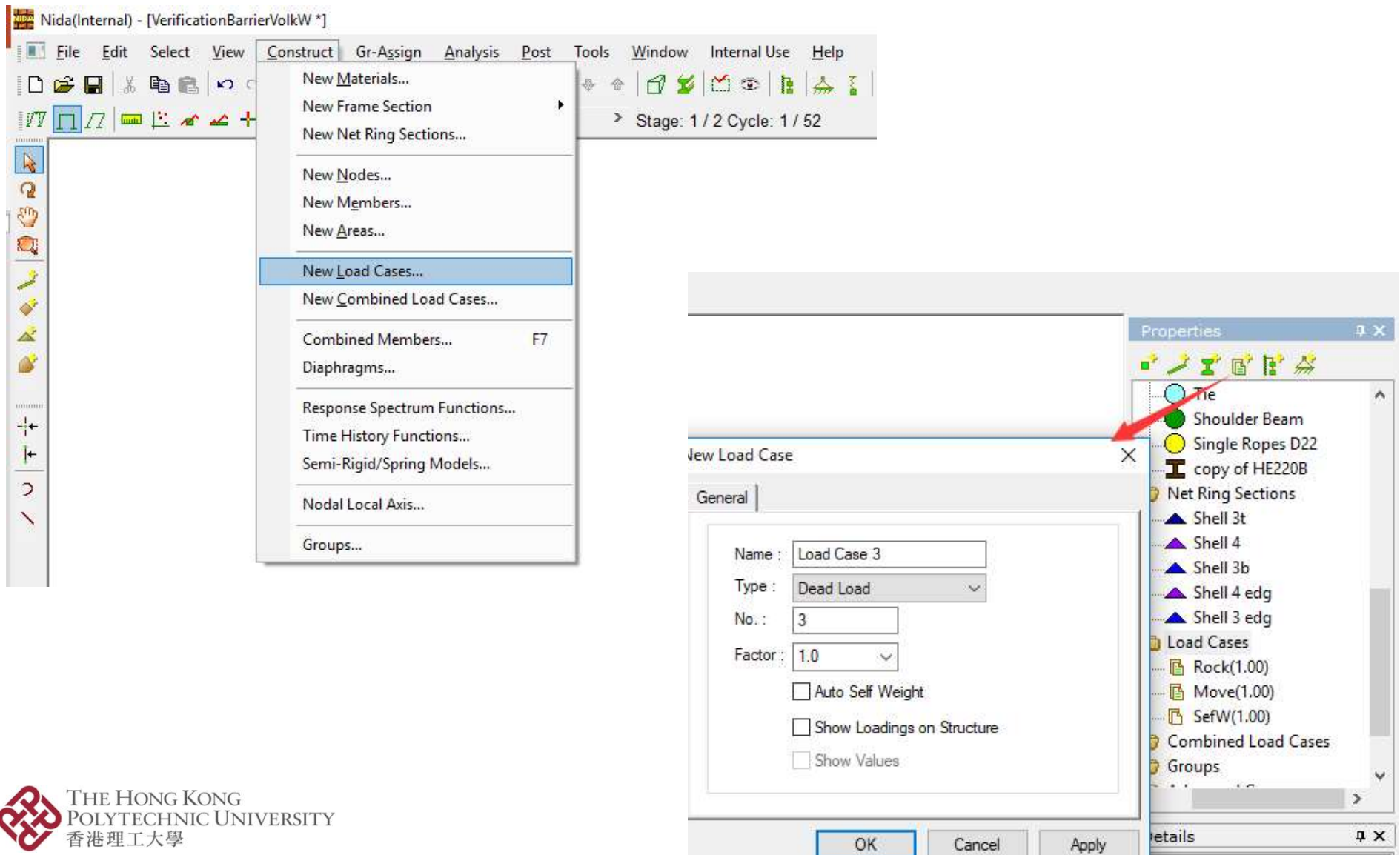
- Tie
- Shoulder Beam
- Single Ropes D22
- copy of HE220B
- Net Ring Sections
 - Shell 3t
 - Shell 4
 - Shell 3b
 - Shell 4 edg
 - Shell 3 edg
- Load Cases
- Combined Load Cases
- Groups
- Advanced Groups
 - Combined Members
 - Diaphragms

Details Panel:

Attributes	Values
Item Type	Combine
No.	4
Name	0 Memb...
No.	4
Starting Node No.	187
Ending Node No.	188
Member list	1 2 3 4 5 6

Add Load

Add Load Case



Add Load

The screenshot displays the Nida software interface. The 'Gr-Assign' menu is open, with 'Nodal Loads' highlighted by a red box. The 'Loading Properties' dialog box is also open, showing settings for a 'Rock' load case of type 'Trapezoidal Load'. The dialog includes options for load distribution (UDL, Trapezoid, Triangle, Quadrangle) and direction (Global/Local, X/Y/Z). A 'Properties' window on the right shows a tree view of the model components, with a red arrow pointing to the 'Tip' component.

Gr-Assign

- Nodes
- Members
- Floors
- Net Rings
- Areas
- Nodal Loads**
- Member Loads
- Floor Pressure...
- Net Ring Pressure...
- Area Pressure...
- Add WindLoad...
- Copy Area Pressures...
- Remove Loads...
- Assign to Group...

Loading Properties

Load Case: Rock

Load Type: Trapezoidal Load

UDL Trapezoid Triangle Quadrangle

Magnitude at Near End (q1): 0.000

Magnitude at Far End (q2): 0.000

Distance from Left (d): 0.000

Length of Distributed Load (c): 0.000

Relative Absolute Whole Length

Axis: Global (Distributed) Global (Projected) Local

Direction: X Y Z

Convert to Nodal Loads directly

Buttons: Apply, Close

Properties

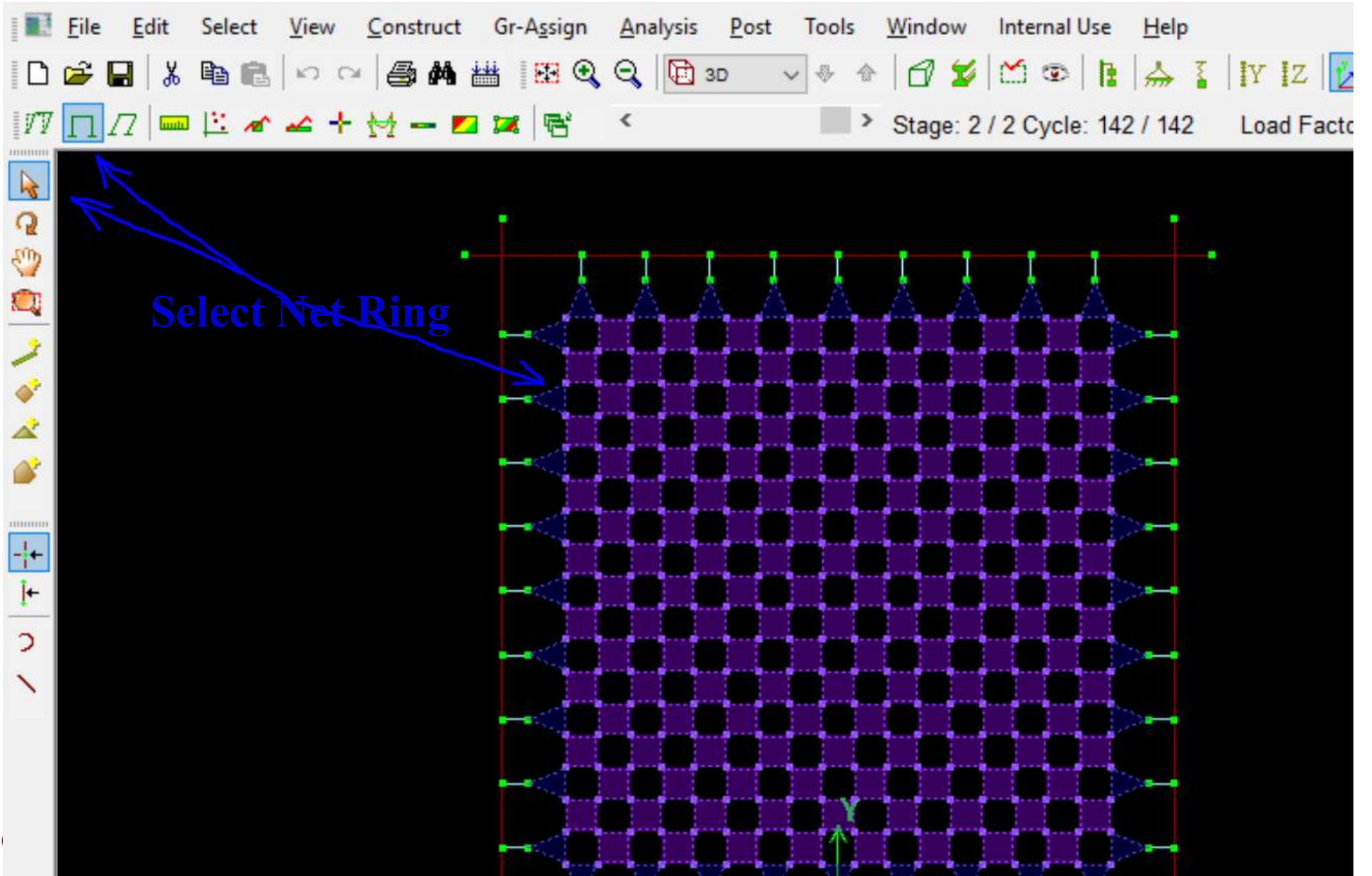
- Tip
- Shoulder Beam
- Single Ropes D22
- copy of HE220B
- Net Ring Sections
 - Shell 3t
 - Shell 4
 - Shell 3b
 - Shell 4 edg
 - Shell 3 edg
- Load Cases
 - Rock(1.00)
 - Move(1.00)
 - SefW(1.00)
- Combined Load Cases
- Groups

Details

Attributes	Values
Item Type	Load Cas
Name	Move
No.	2
Factor	1.00000

6 Analysis & Design of Flexible Barriers

Nida(Internal) - [VerificationBarrierVolkW.dat]



6 Analysis & Design of Flexible Barriers

Stage: 2 / 2 Cycle: 142 / 142 Load Factor: 1.0000

Loading Properties

Load Case: DebrisFlow

Load Type: Pressure on Area Object

All Floors Rings Areas

Pressure: -30

Direction

Global Axis X Y Z

Normal

Convert to Member Loads first

Convert to Nodal Forces directly

Note: Area pressure are invalid in analysis before the areas are converted to floor/shell elements.

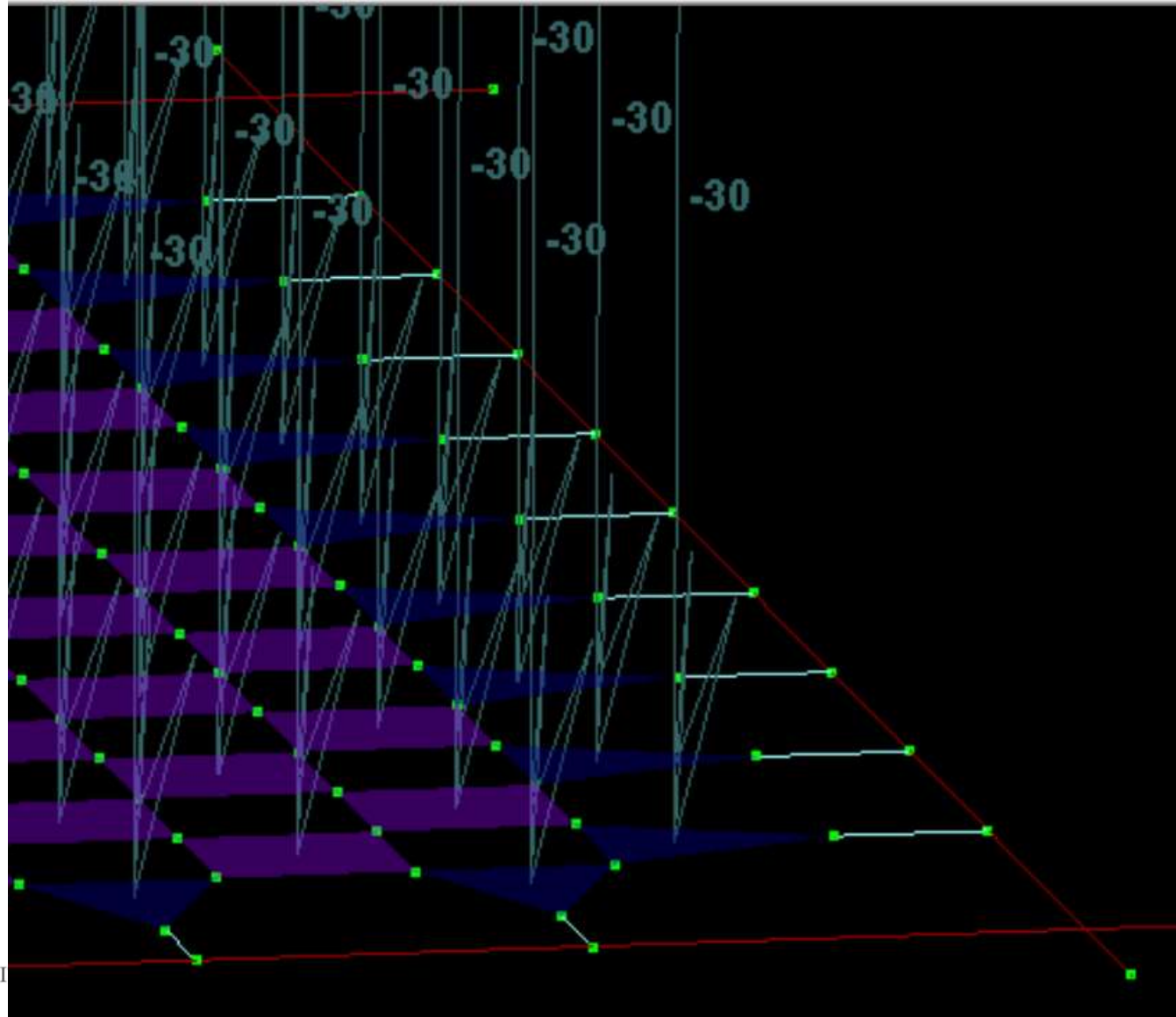
Apply Close

Properties

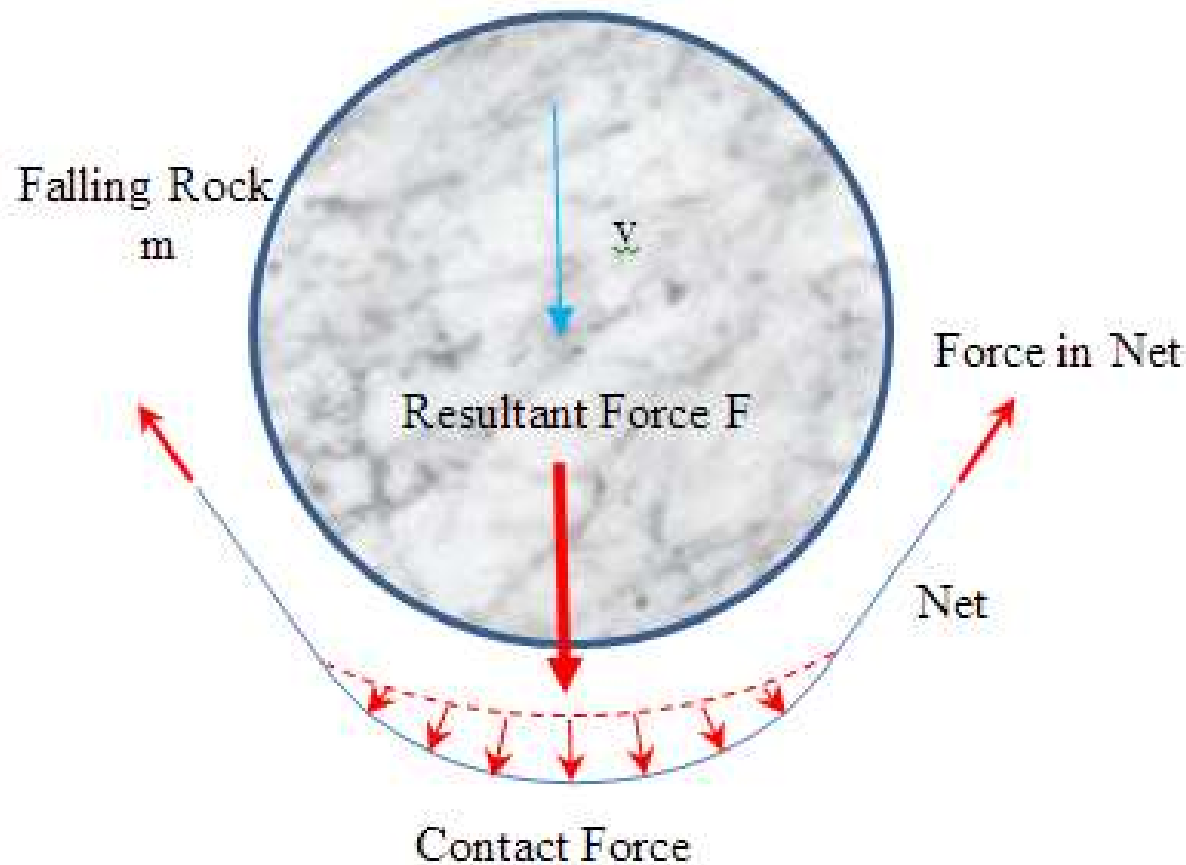
- Bottom Ropes 3E
- Border Ropes 2D
- Retain Ropes 2D
- HE220B
- Tie
- Shoulder Beam
- Single Ropes D22
- copy of HE220B
- Net Ring Sections
- Load Cases

Attributes	Values
------------	--------

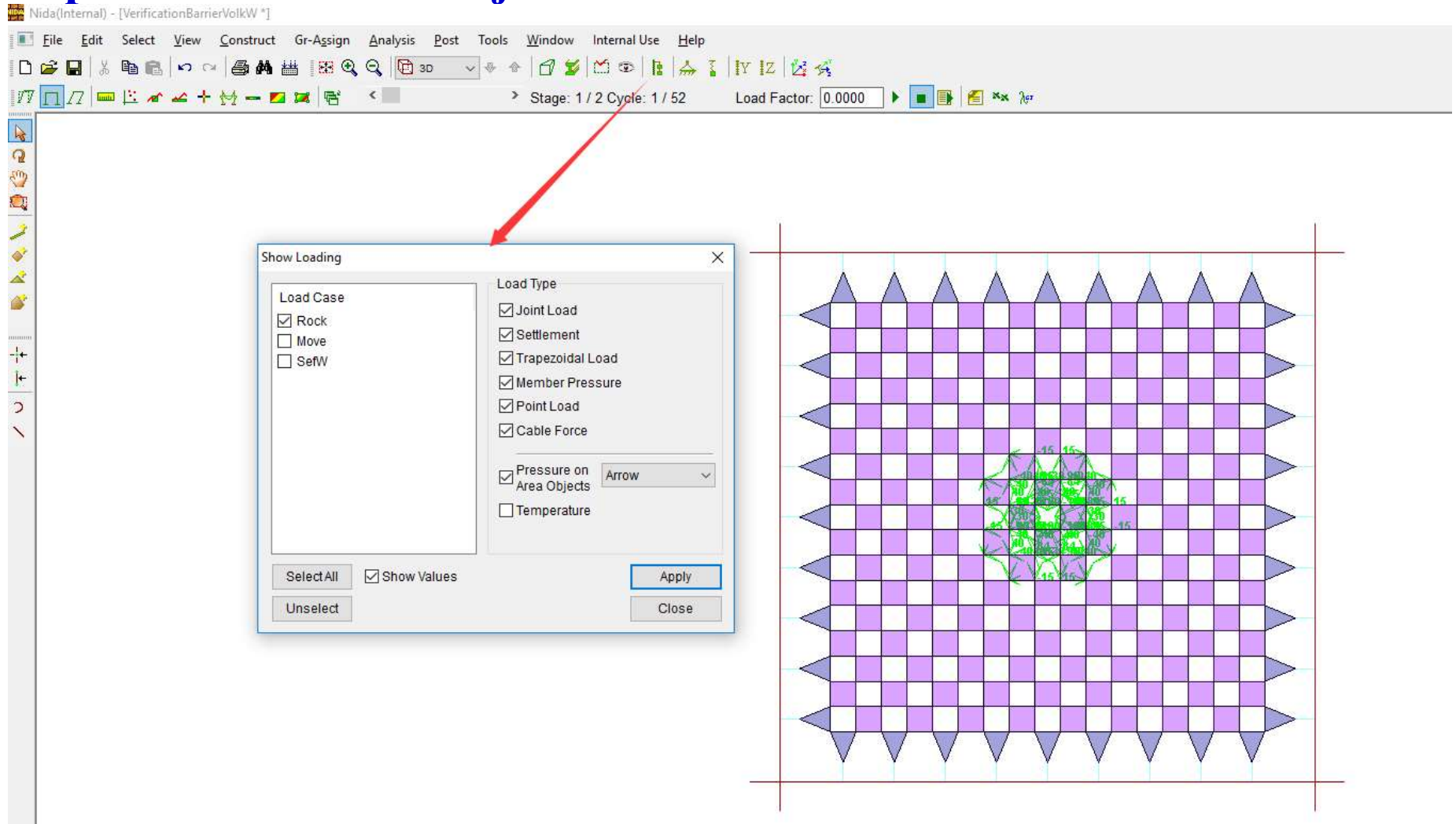
Show Loading



Impact force of rock – joint load



Impact force of rock – joint load



Set Analysis Case

Analysis Case

The screenshot displays the software interface for configuring an analysis case. The main menu bar includes File, Edit, Select, View, Construct, Gr-Assign, Analysis, Post, Tools, Window, Internal Use, and Help. The 'Analysis' menu is open, showing options like Run (F5), Run a Batch of Files..., Set Analysis Cases..., and Analysis & Design Parameters Setting... The 'Set Analysis Cases...' option is highlighted.

The 'Analysis Cases' dialog box is open, showing a list of cases. 'DebrisFlowAnalysis' is selected and highlighted in blue. A red box highlights this entry. Below the list are 'Edit' buttons: Add, Modify..., Duplicate, Rename, and Delete. At the bottom, 'Use Processors' is set to 8.

The 'DebrisFlowAnalysis' configuration dialog box is open, showing the following settings:

- Name: DebrisFlowAnalysis
- Type: Second-order Analysis Only
- PEP Element Curved Stability Function
- Enable Plastic Advanced Analysis Plastic Element Plastic Hinge
- Total Load Cycles: 200
- Number of Iterations for each Load Cycles: 100
- Number of Iterations for Tangent Stiffness Matrix: 1
- Incremental Load Factor: 1e-007
- Numerical Method: Arc Length Method + Minimum Residual Displacement Method
- Iterative & Incremental Parameters: Load Size of First Step: 30, Maximum Arc Distance: 0.3
- Minimum Member Imperfection * L / 1000: 1
- Imperfection Method & Direction: No Imposition of initial imperfection

The 'Applied Loads' dialog box is open, showing a table of loads applied:

Name	Type	Factor
DebrisFlow	Load Case	1.00

A red box highlights the 'DebrisFlow' entry in the table. Below the table are navigation buttons: 1.00, >>, <<, ALL >>, and ALL <<. At the bottom, there is a checkbox for 'Enable Load/Construction Stage' which is currently unchecked.

Analysis Case

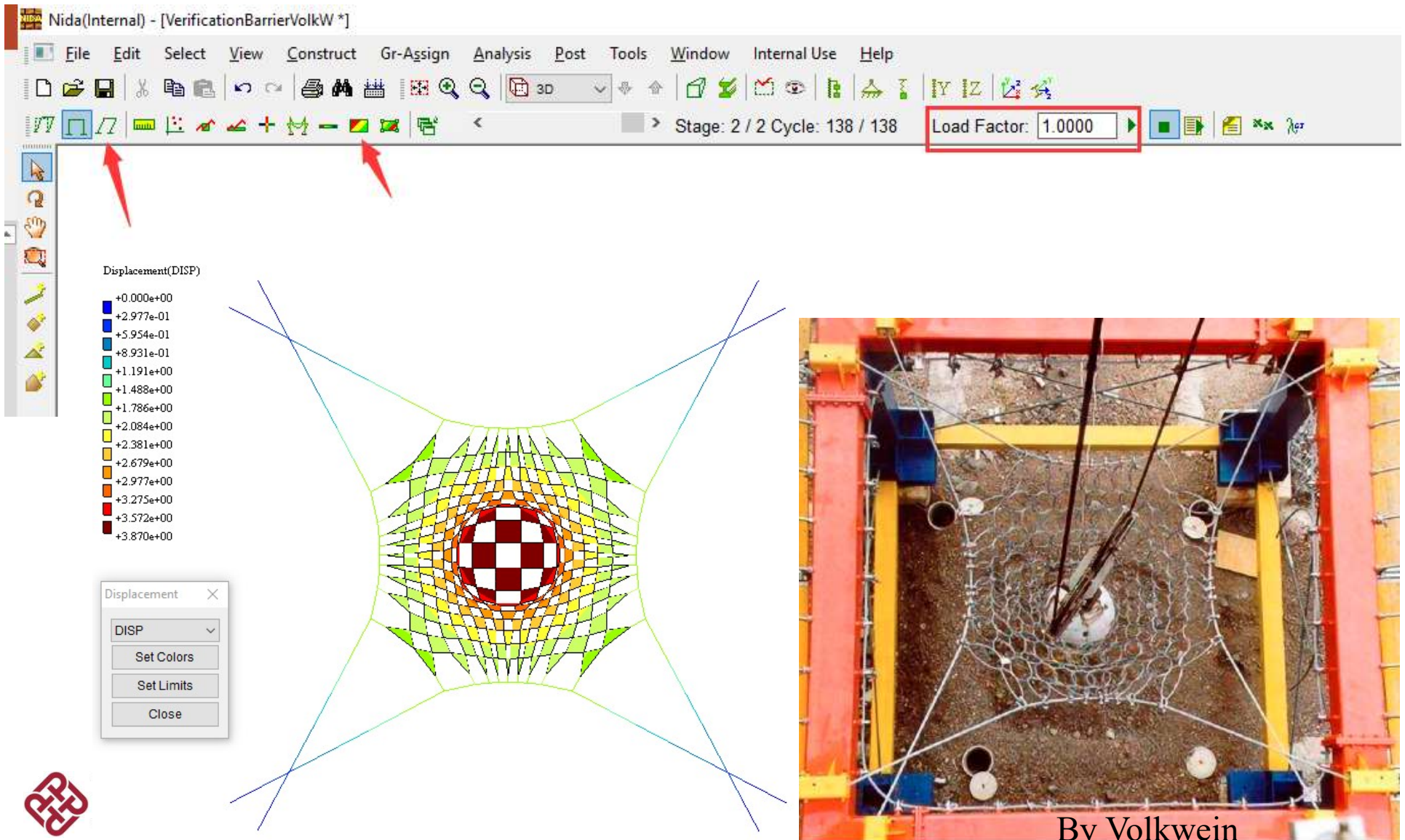
The screenshot displays the Nida software interface with the following components:

- Analysis Cases Dialog (D800rockFall):**
 - Name: D800rockFall
 - Type: Second-order Analysis Only
 - Method: PEP Element
 - Iterative & Incremental Parameters:
 - Total Load Cycles: 150
 - Number of Iterations for each Load Cycles: 100
 - Number of Iterations for Tangent Stiffness Matrix: 1
 - Incremental Load Factor: 1e-007
 - Minimum Member Imperfection * L / 1000: 1
 - Imperfection Method & Direction: No Imposition of initial imperfection
- Applied Loads Dialog:**
 - Loads Applied Table:

Name	Type	Factor	Load...
SefW	Load Case	1.00	1
Rock	Load Case	0.15	2
 - Enable Load/Construction Stage

ions, LOAD STAGE = -1;For construction stages, LOAD STAGE = -2

Nodal Displacement Contour



Nodal Deflection

The screenshot displays the NIDA software interface for a Second-Order Analysis. The 'Applied Loads' window is active, showing a table of loads applied to the model. The 'Nodal Deflection / Reaction' window is also open, showing a 'Loading Factor' vs 'Deflection' curve for node 252.

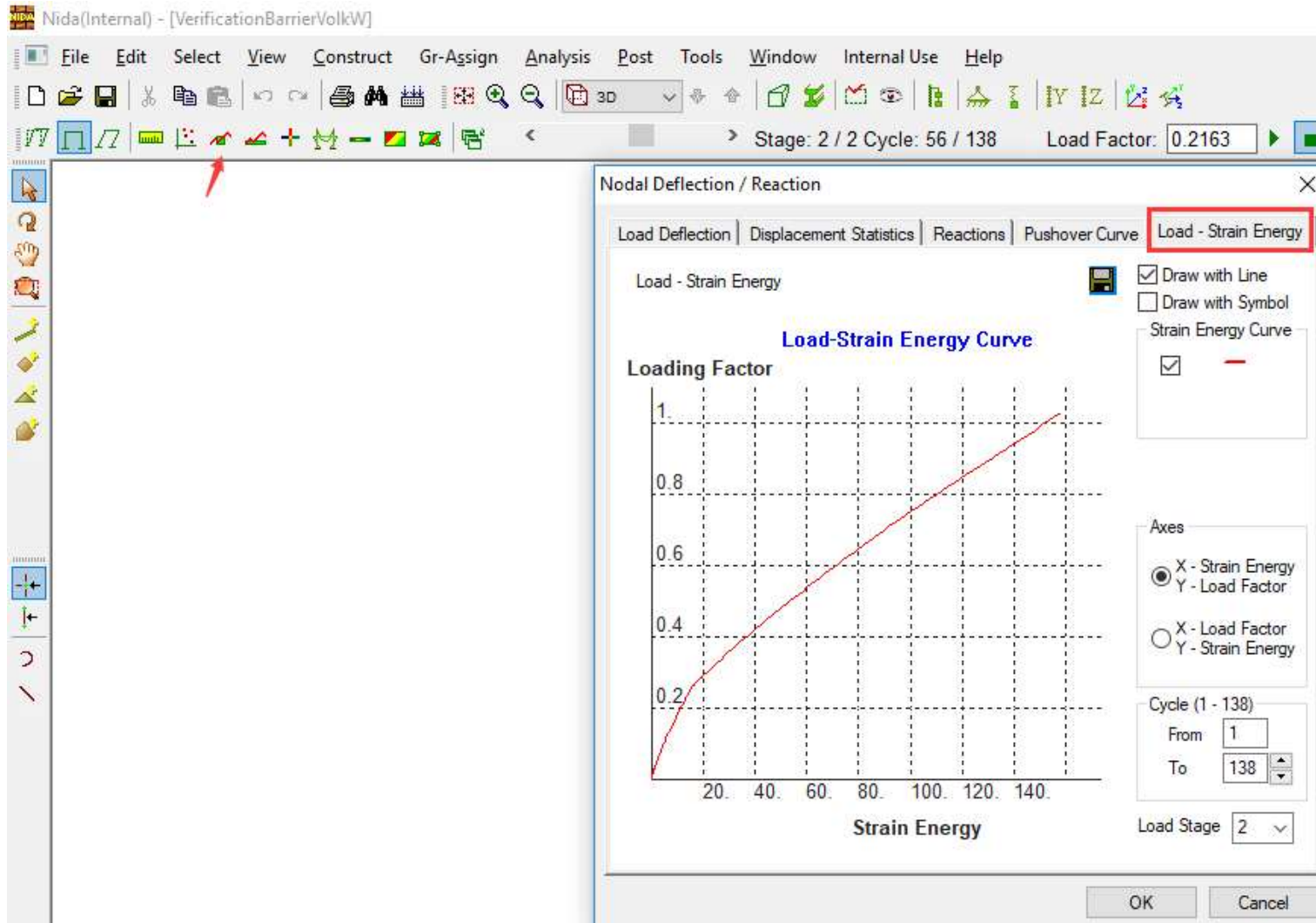
Applied Loads Table:

Name	Type	Factor	Load...
SefW	Load Case	1.00	1
Rock	Load Case	0.15	2

Nodal Deflection / Reaction Window:

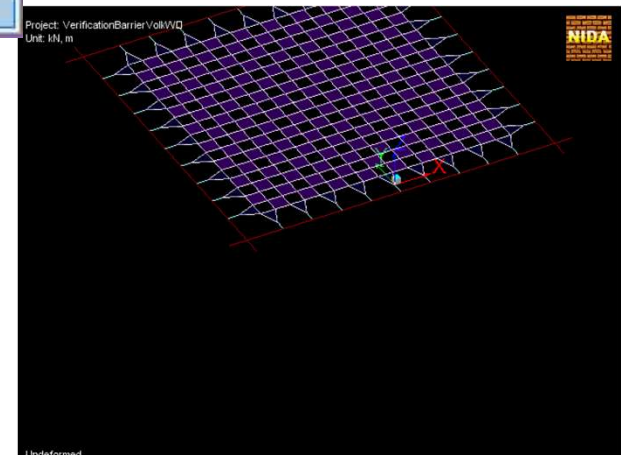
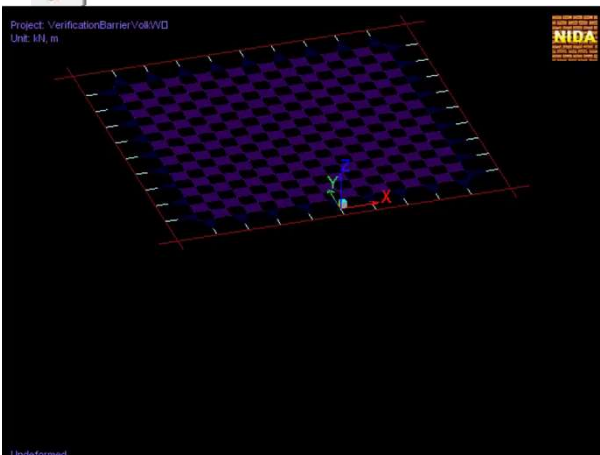
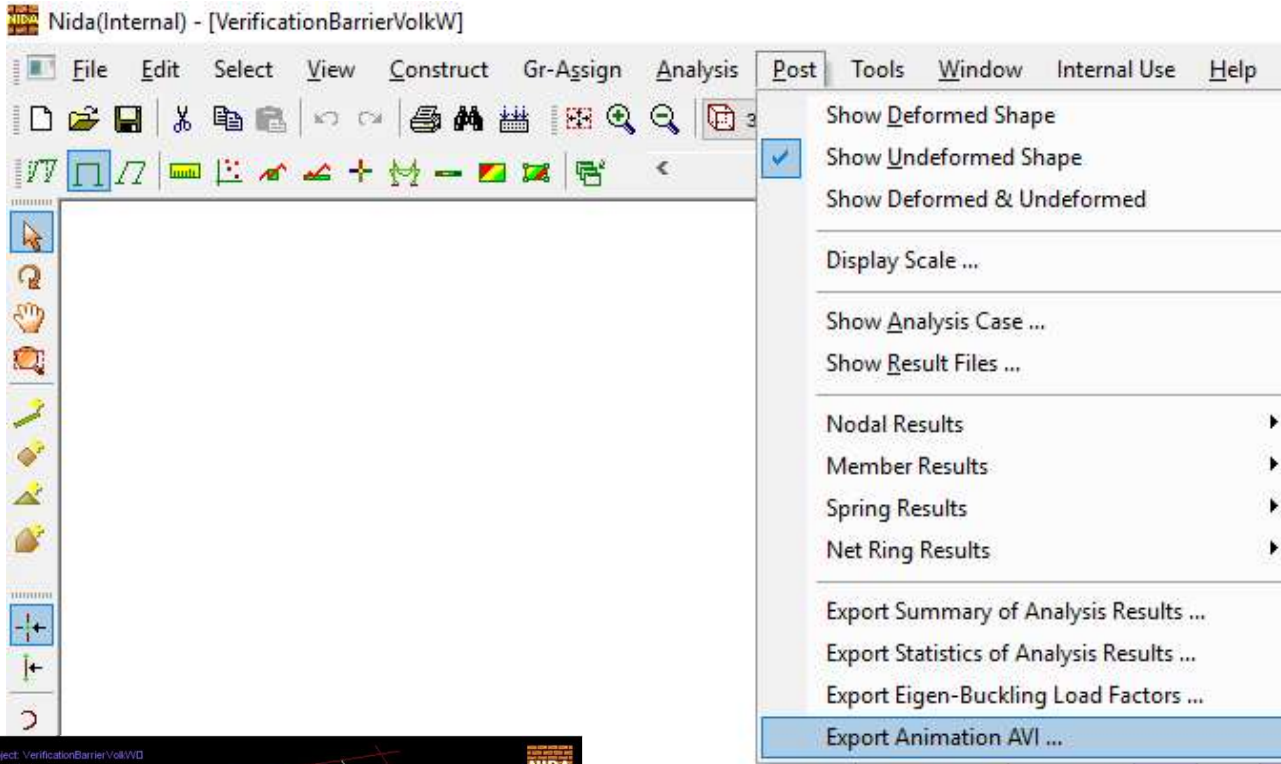
- Node: 252
- Coordinates: x=-0.100442 y=2.05044 z=0
- Graph: Loading Factor vs Deflection
- Y-axis: Loading Factor (0 to 1)
- X-axis: Deflection (-4 to 0)
- Legend: UZ (blue line)
- Axis Selection: X - Deflection, Y - Load Factor
- Cycle (1 - 138): From 1, To 138
- Load Stage: 2

Nodal Deflection

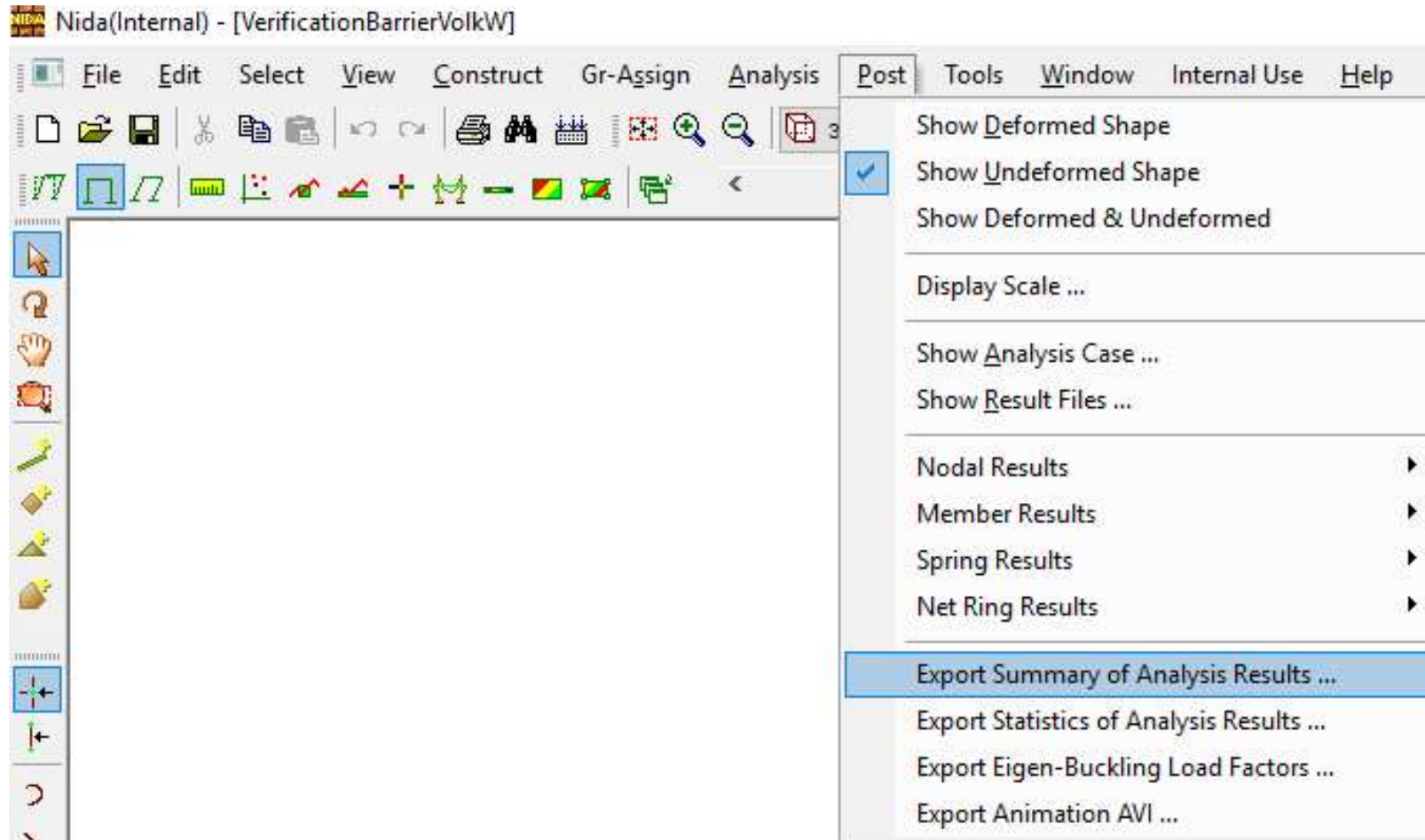


6 Analysis & Design of Flexible Barriers

Export Animation AVI



Others: Reaction Forces, Result Data Output





THANK YOU

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Design Experience Sharing of A Selected Project



Ir Dr Raymond Koo & Ir Dr Eric Sze

Geotechnical Engineer

GEOTECHNICAL ENGINEERING OFFICE

Date: 16 April 2019

Outline



1. Project Background

**2. Design using Force Approach
(NIDA-MNN)**

**3. Design Optimisation using
Coupled Analysis (LS-DYNA)**

Eric

Raymond

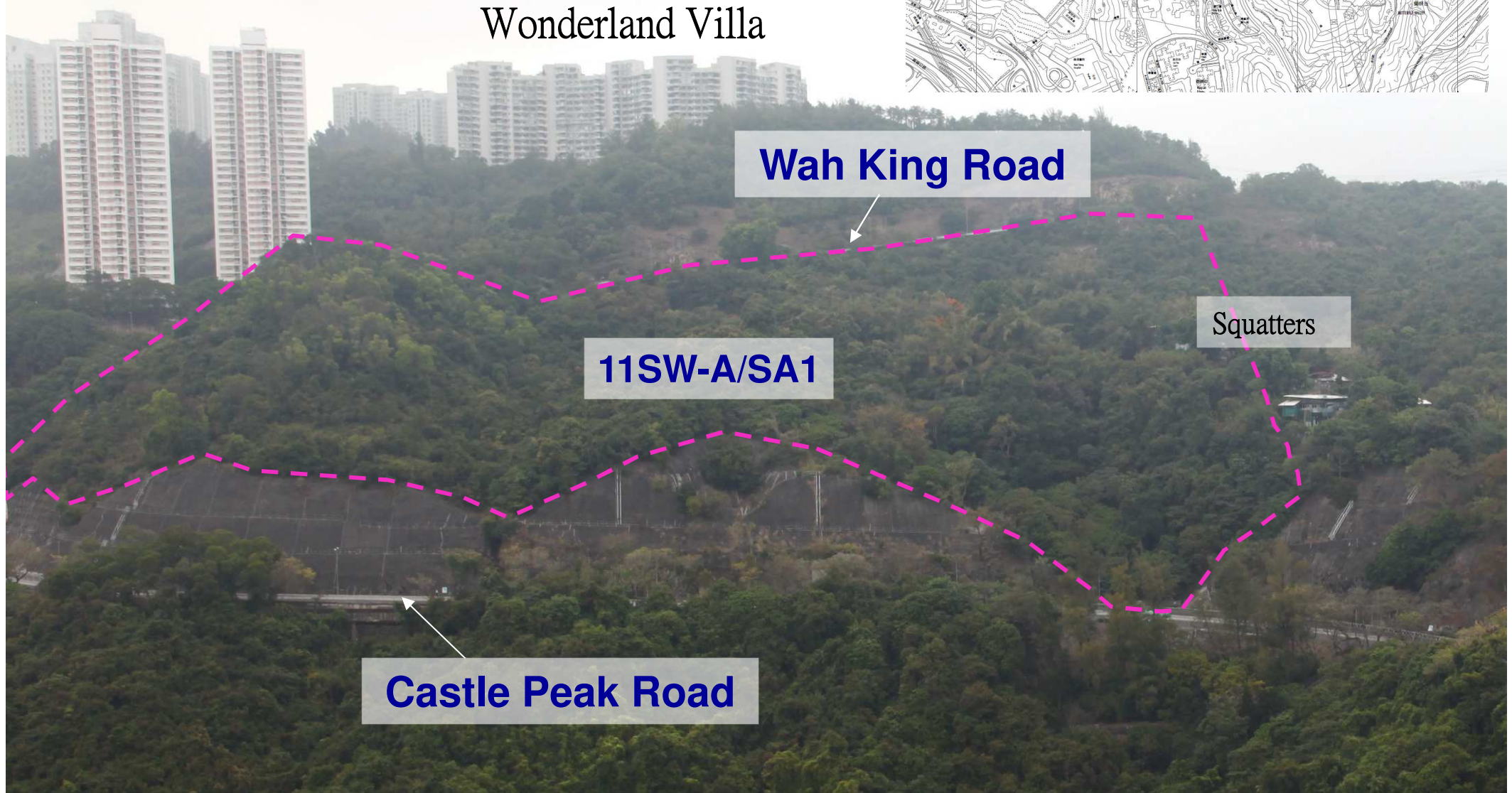
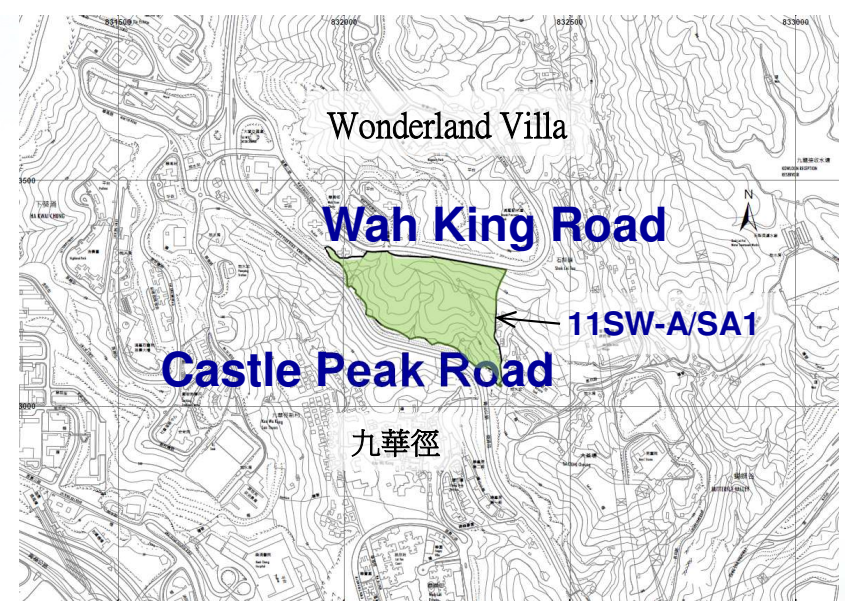
1. Project Background



In-house LPMit Project

Site constraints:

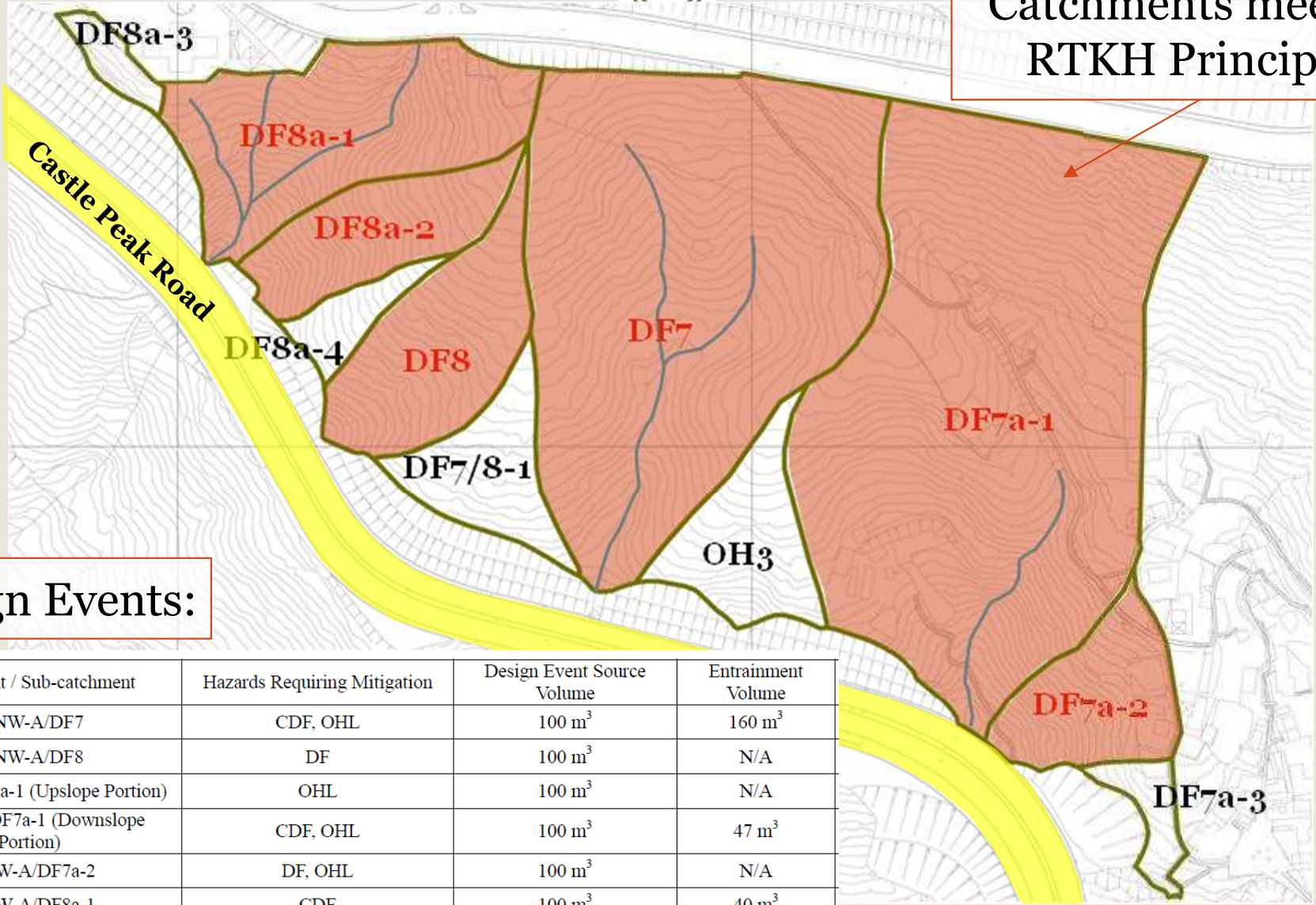
- Squatter, Private Lot, Existing Soil Nails



Key Findings of NTHS



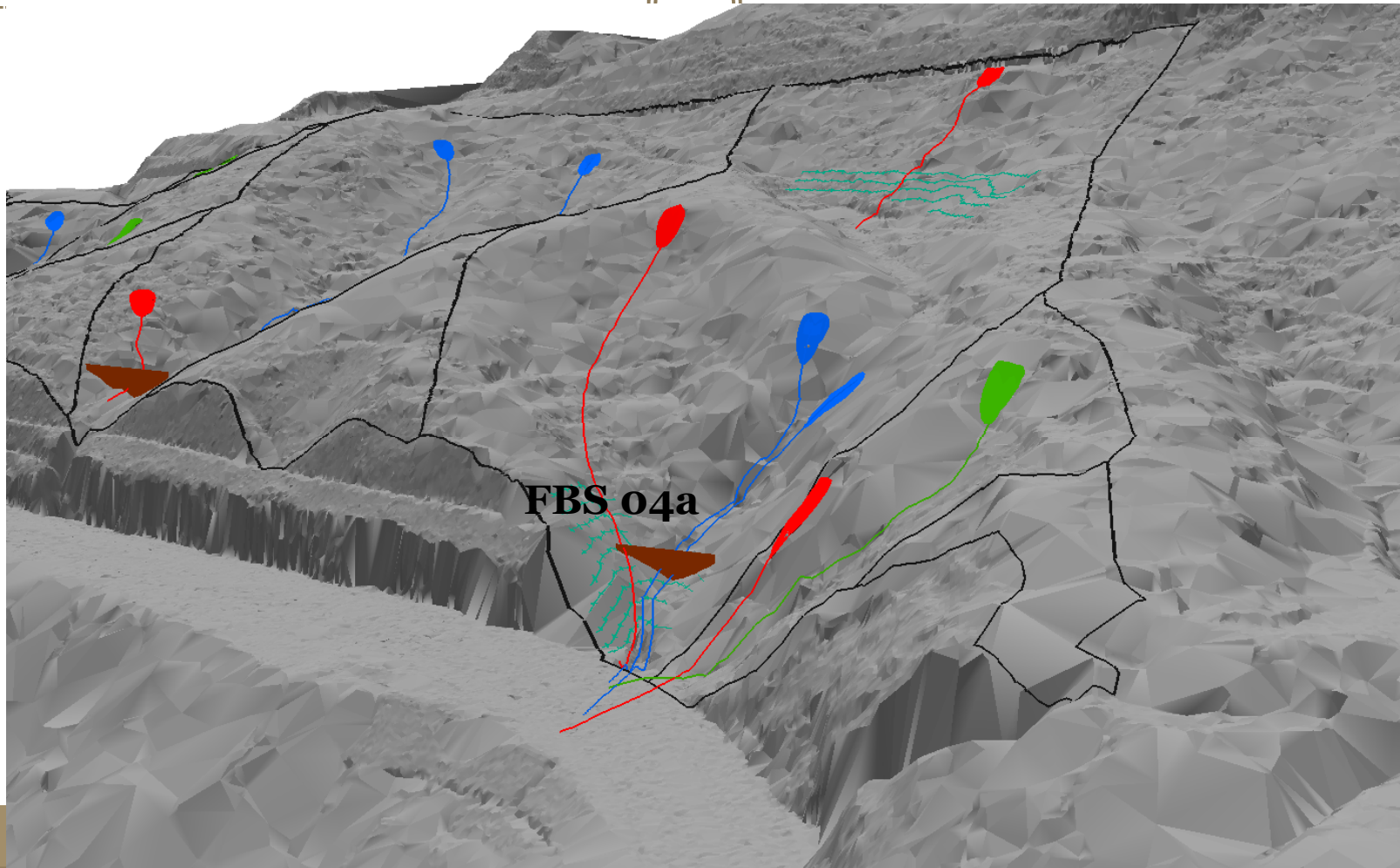
Catchments meeting RTKH Principles



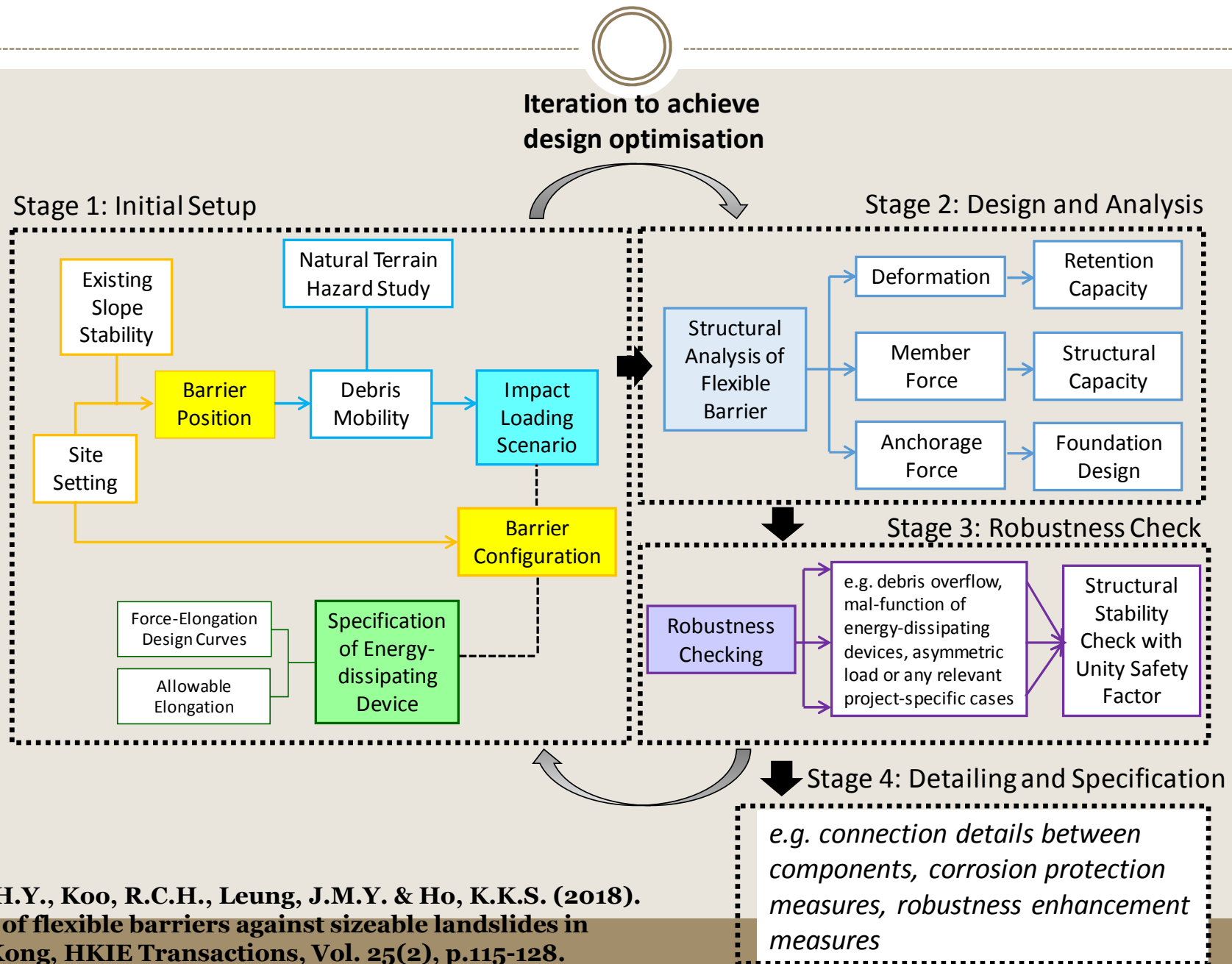
Design Events:

Catchment / Sub-catchment	Hazards Requiring Mitigation	Design Event Source Volume	Entrainment Volume
11NW-A/DF7	CDF, OHL	100 m ³	160 m ³
11NW-A/DF8	DF	100 m ³	N/A
11NW-A/DF7a-1 (Upslope Portion)	OHL	100 m ³	N/A
11NW-A/DF7a-1 (Downslope Portion)	CDF, OHL	100 m ³	47 m ³
11NW-A/DF7a-2	DF, OHL	100 m ³	N/A
11NW-A/DF8a-1	CDF	100 m ³	40 m ³
11NW-A/DF8a-2	DF	100 m ³	N/A

2. Design Using Force Approach

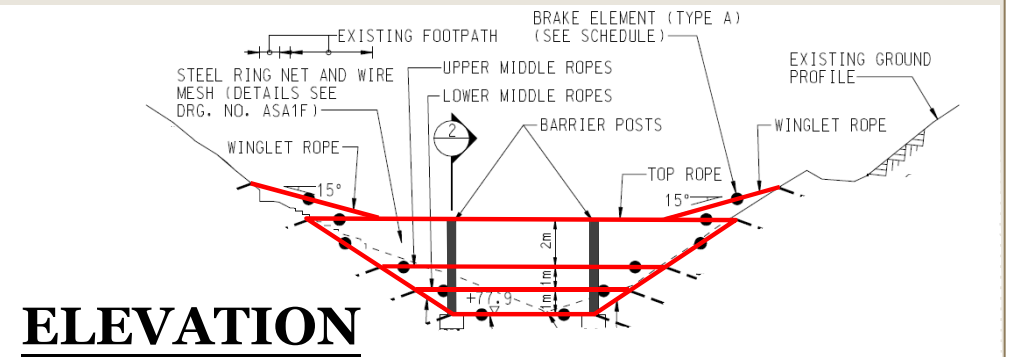
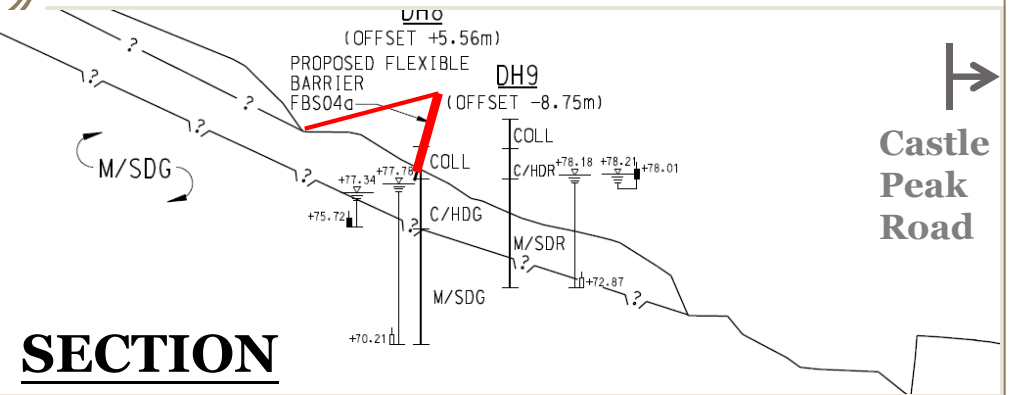
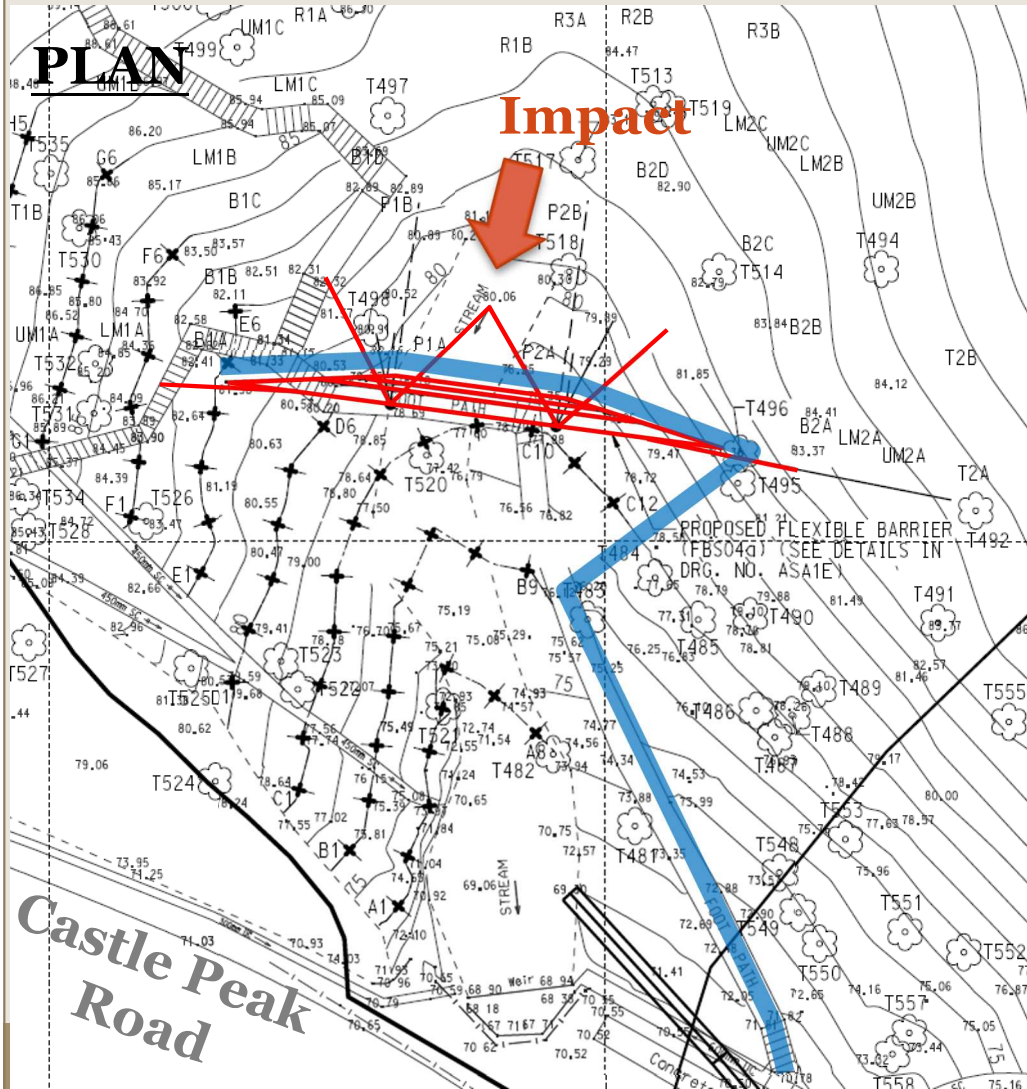


General Design Procedures



Site Setting

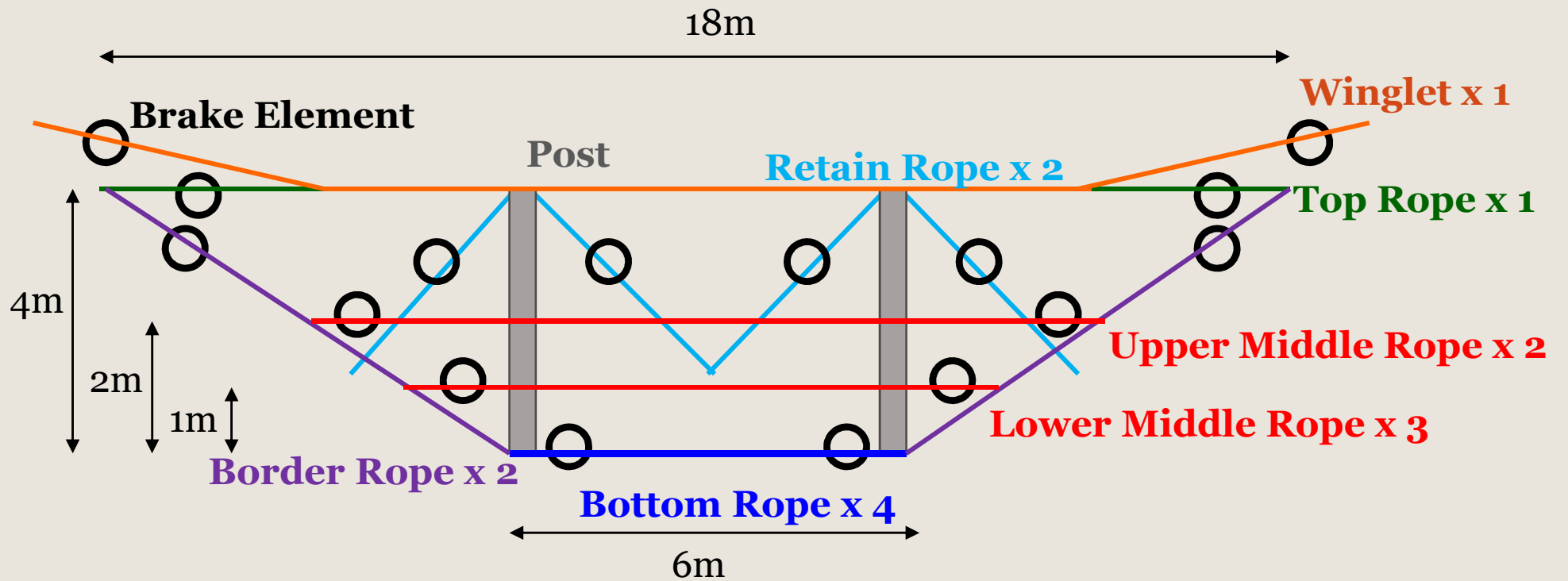
• FBS04a



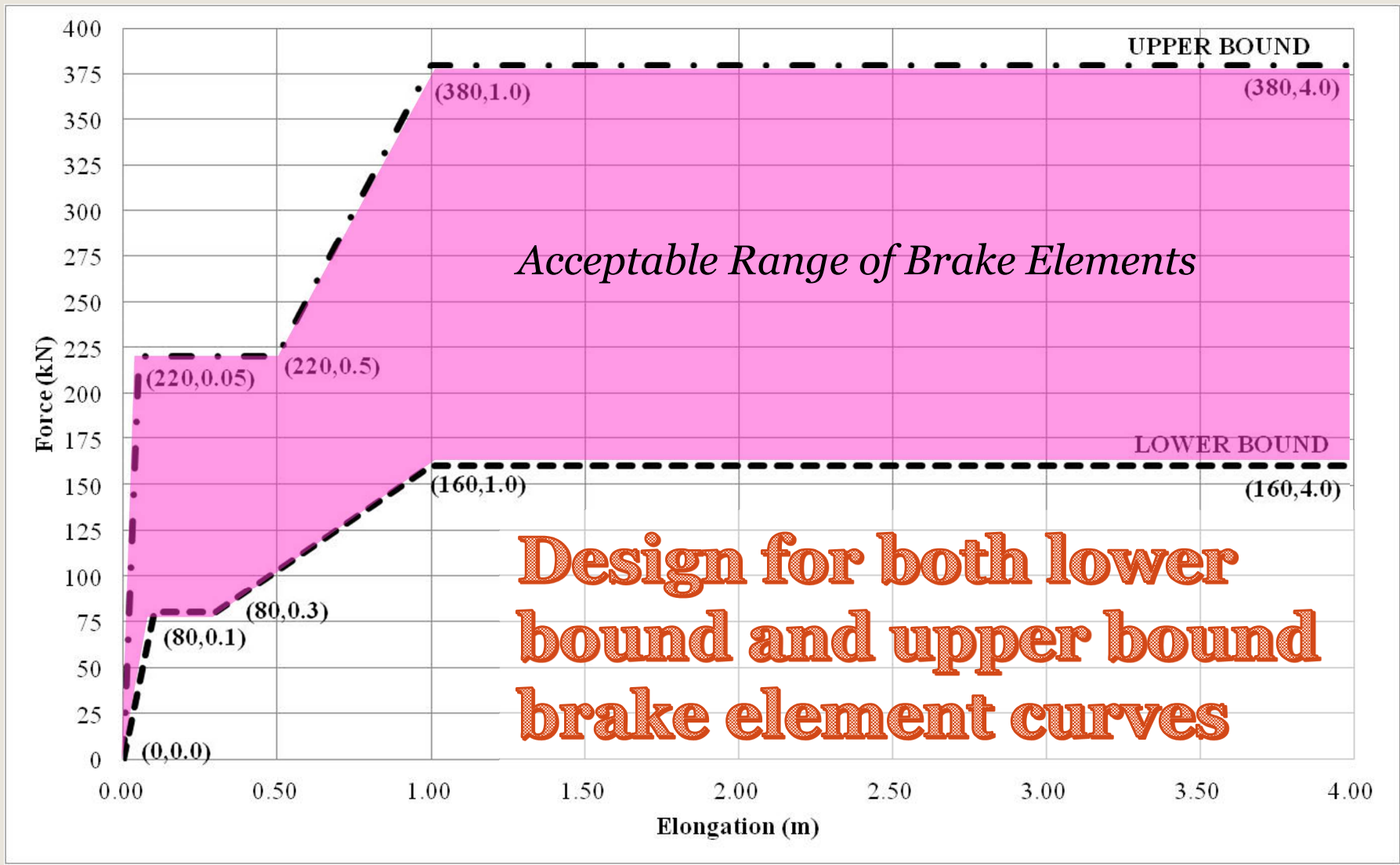
Barrier Layout



- Rope, Ring Net, Brake Element Arrangement



Design Force-Elongation Curve for Brake Elements

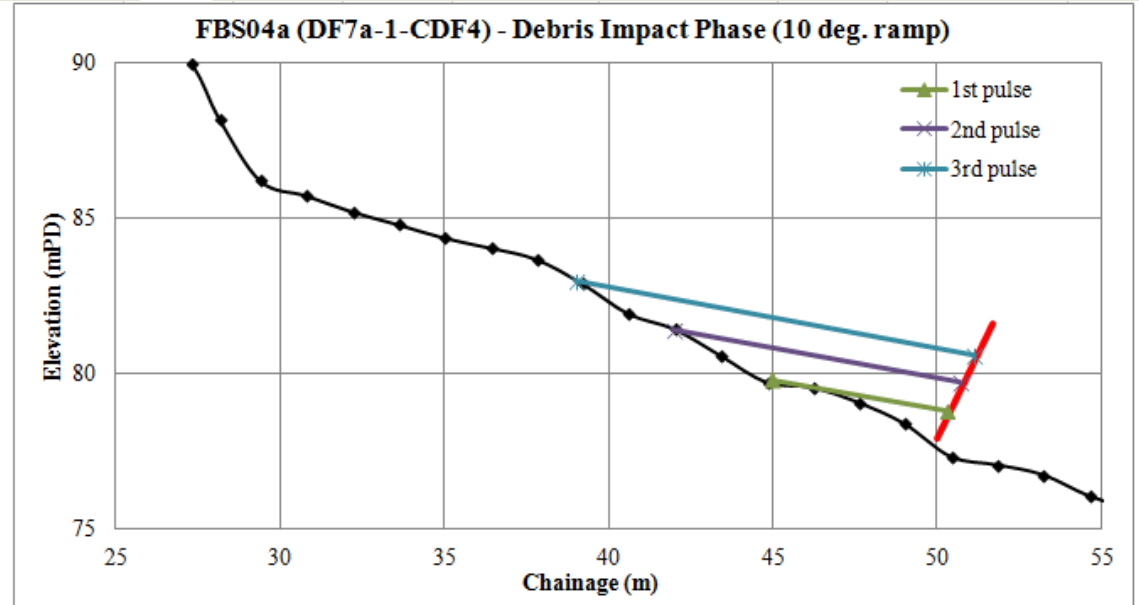


Impact Volume and Retention Capacity

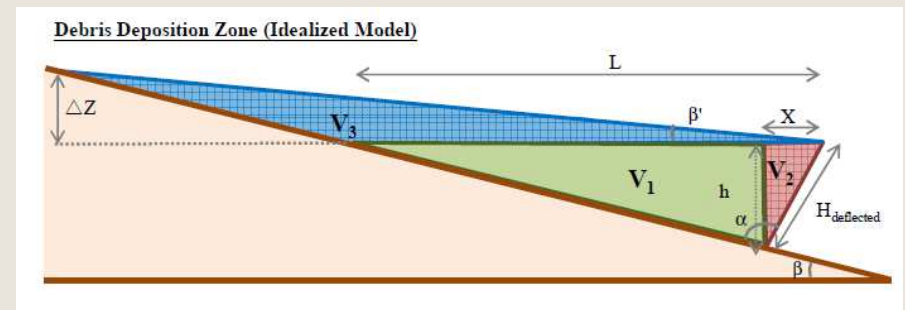


Definition of Debris Impact Ramp (Each Phase)
 According to DNI/2012,
 Taking debris ramp impact at 10 deg.

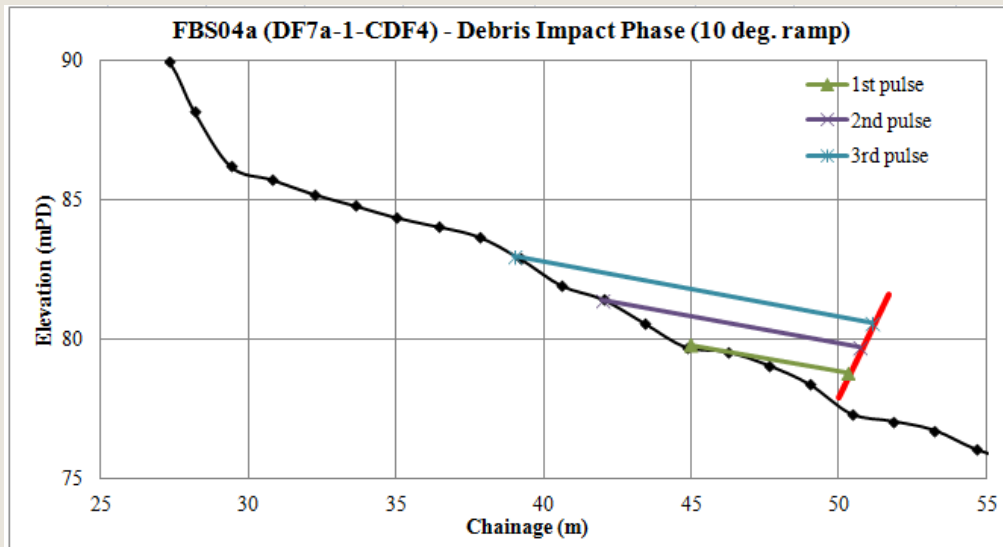
Calculation of Design Debris Impact Height and No. of Impact Phases
 Total Debris Impact Volume = 138.9 m³ \ 8% Bulking
 According to Table below,
 Total Ramp Volume = 197.3 m³ Factor (GEO Report 104)
 under Impact Phase No. 3
 Therefore,
 No. of Design Impact Phases = 3
 Height of Design Impact Phases = 3.0 m



- Later modelling found that barrier sags by 1 m, hence the retention capacity of the deflected barrier = **252 m³**
 - Actual topography considered
 - Barrier dimensions considered
 - Bulged-out volume ignored



Design Impact Scenario



Consideration of impact velocity reduction (TGN44)

No. of Phase	Vol. of Individual Phase	Cul. Vol. of Phases	Impact Duration	Design Velocity	Dynamic Pressure
	(m ³)	(m ³)	(s)	(m/s)	(kPa)
1	24	24	6.77	9.5	397.1
2	70	93	8.91	8.1	288.7
3	159	253	Completed	6.7	197.5

1st Phase

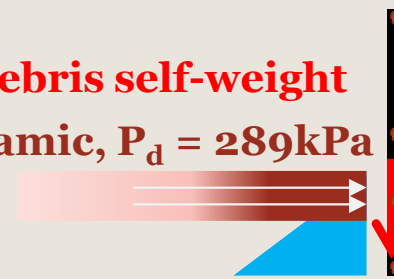
Barrier



Dynamic, $P_d = 397\text{kPa}$

2nd Phase

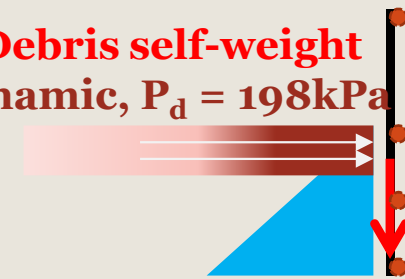
**Debris self-weight
Dynamic, $P_d = 289\text{kPa}$**



Static, $P_s = 26\sim 43\text{kPa}$

3rd Phase

**Debris self-weight
Dynamic, $P_d = 198\text{kPa}$**



Static, $P_s = 26\sim 65\text{kPa}$

NIDA-MNN Model

Assign Brake Elements

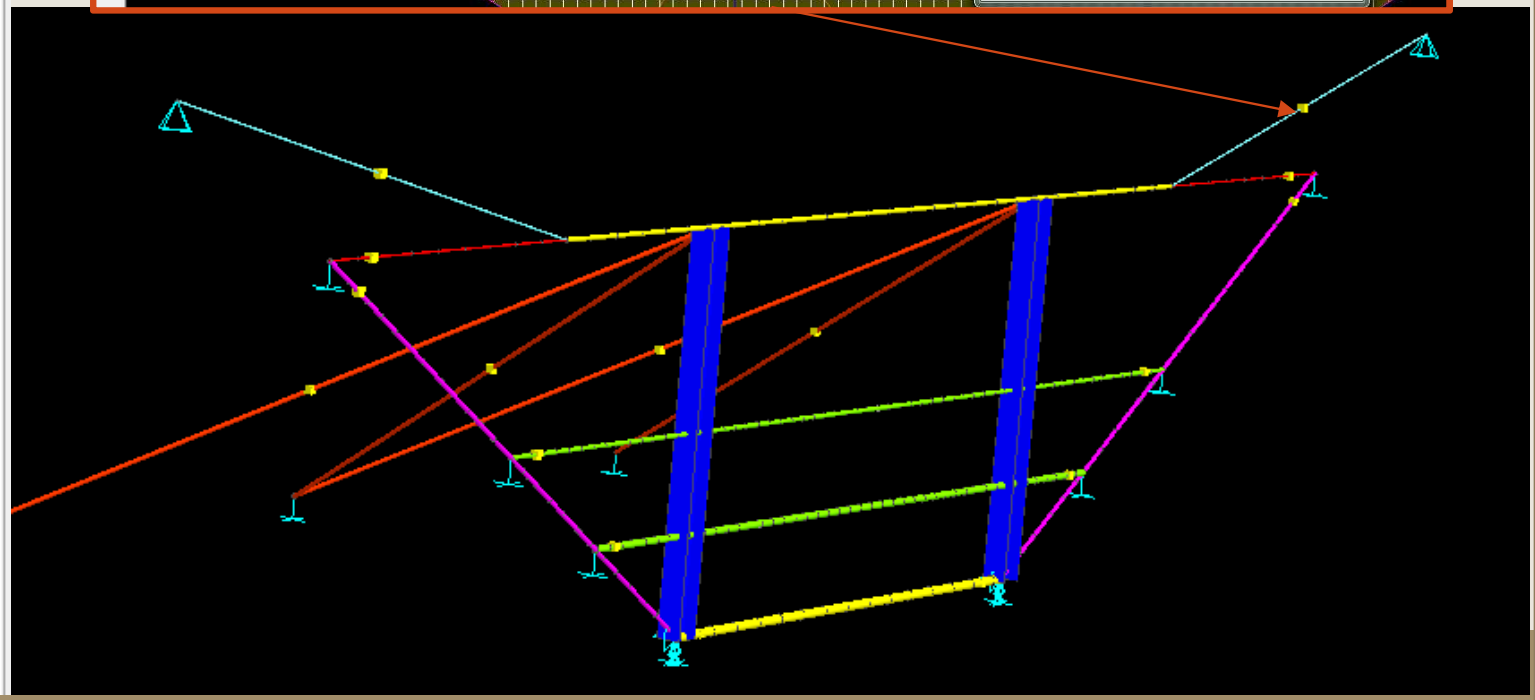
Material & Section Properties

Properties

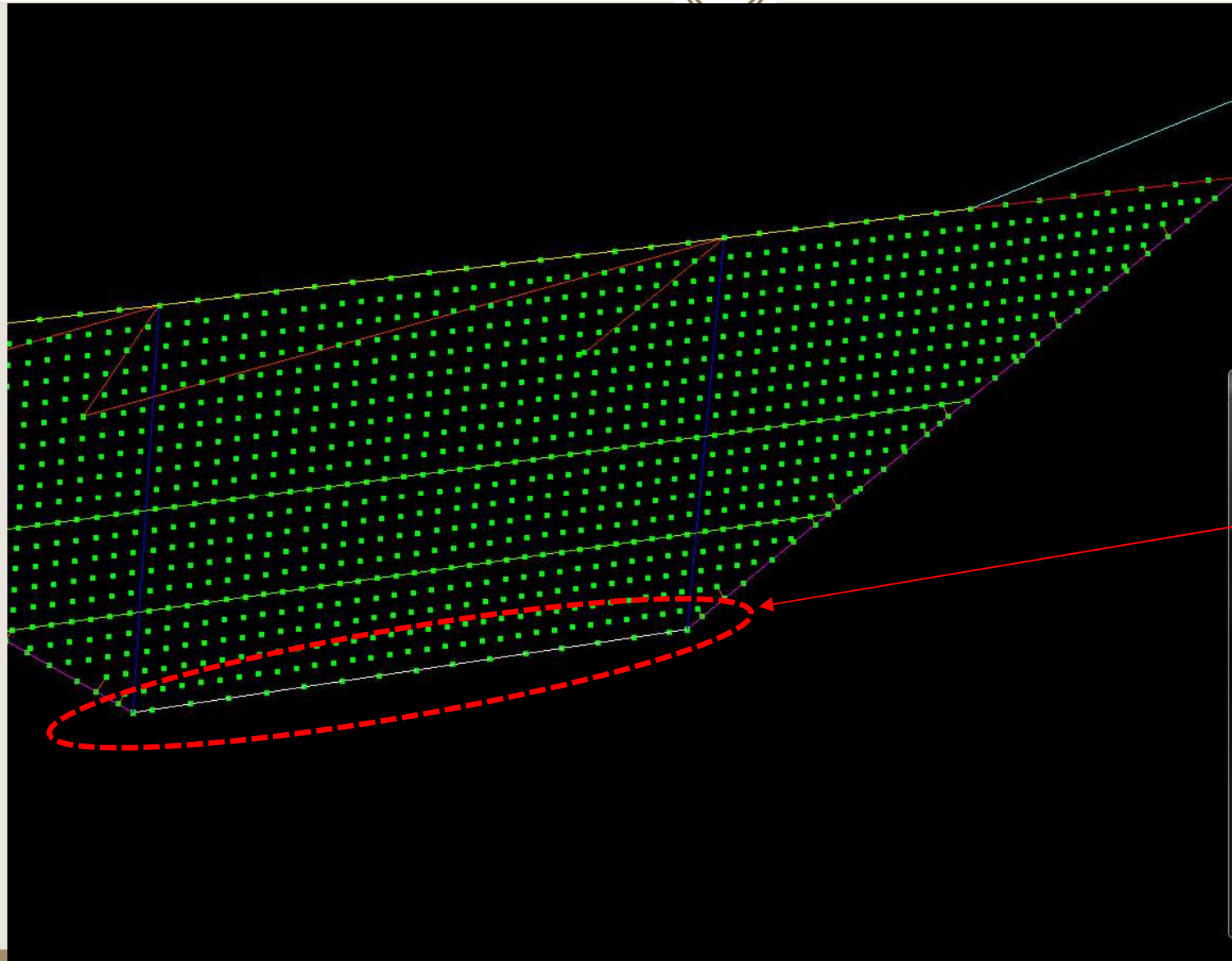
- 20150913-DF7a-1_FBS04a_D&R1_UB1m
 - Materials
 - S275
 - Ring
 - Cable
 - Frame Sections
 - Ringnet_4
 - Ringnet_3t
 - Ringnet_3b
 - Ringnet_3edge
 - Ringnet_4edge
 - Upper Middle Rope 2D32
 - Border Rope 2D32
 - Bottom Rope 4D32
 - Combined Rope 2D32
 - Lower Middle Rope 3D32
 - Retain Rope 2D32
 - UC254x254x89
 - Tie
 - Top Rope 1D32
 - Winglet 1D32
 - do not use
 - Net Ring Sections
 - Ringnet_4
 - Ringnet_3t
 - Ringnet_3b
 - Ringnet_3edge
 - Load Cases
 - Combined Load Cases
 - Groups
 - Advanced Groups

The screenshot shows the software interface with the 'Define Semi-Rigid/Spring Models' dialog box open. The 'Type' is set to 'Force-Displacement' and the 'Model' is 'Multi-linear Model'. The 'List' contains '1xUB1m', '2xUB1m', '3xUB1m', and '4xUB1m'. The 'Force-Displacement' graph shows a multi-linear relationship between Force and Displacement. The 'Name' is '1xUB1m' and the 'Initial Elastic Stiffness (Ke)' is '4.4e+003'. The graph data is as follows:

Force	Displacement
0.000	0.00
160.000	0.20
320.000	0.61
480.000	0.81
640.000	1.01



A tricky issue



Properties

- 20150913-DF7a-1_FBS04a_D&R1_UB1m
 - Materials
 - Frame Sections
 - Net Ring Sections
 - Load Cases
 - Combined Load Cases
 - 1st Phase
 - 2nd Phase
 - 3rd Phase
 - 4th Phase
 - Overflow
 - Groups
 - Advanced Groups
 - Combined Members
 - Diaphragms

Combined Members

No.	Start No...	End No...	No. of M...
1	34	1376	29
2	47	33	29
3	1095	37	59
4	1	56	45
5	47	34	16
6	796	1376	8
7	33	214	9
8	214	796	28

Buttons: Add, Delete, Copy to Clipboard, Select, Check Overlap, Check Duplicated

Options: Angle > 175 Same Section

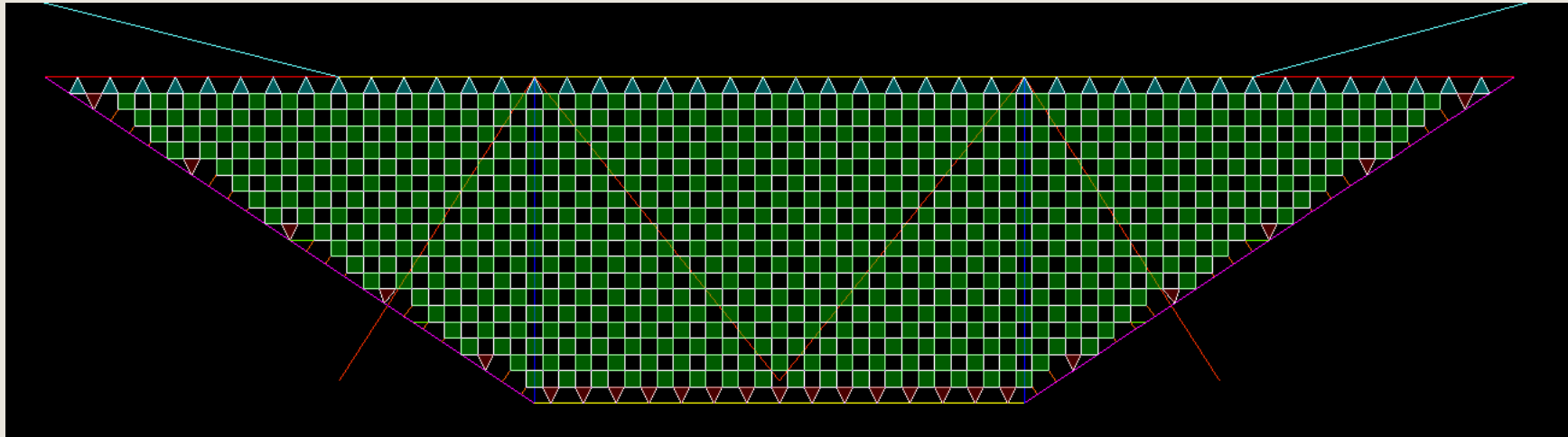
3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

Close

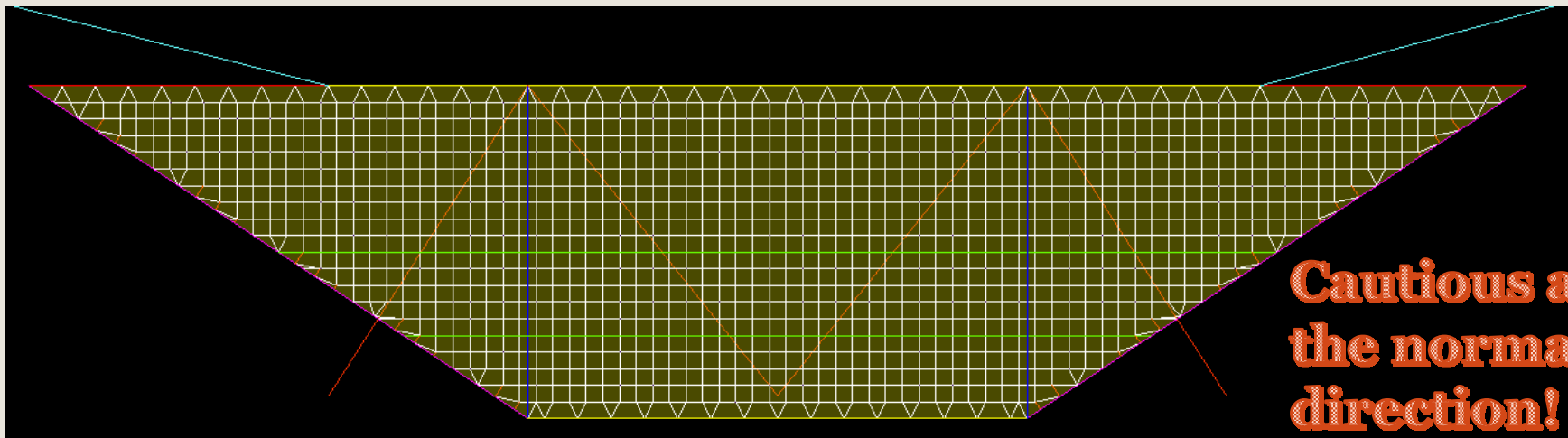
Loading Assignment



A full barrier model



Use of floor element (for load assignment)

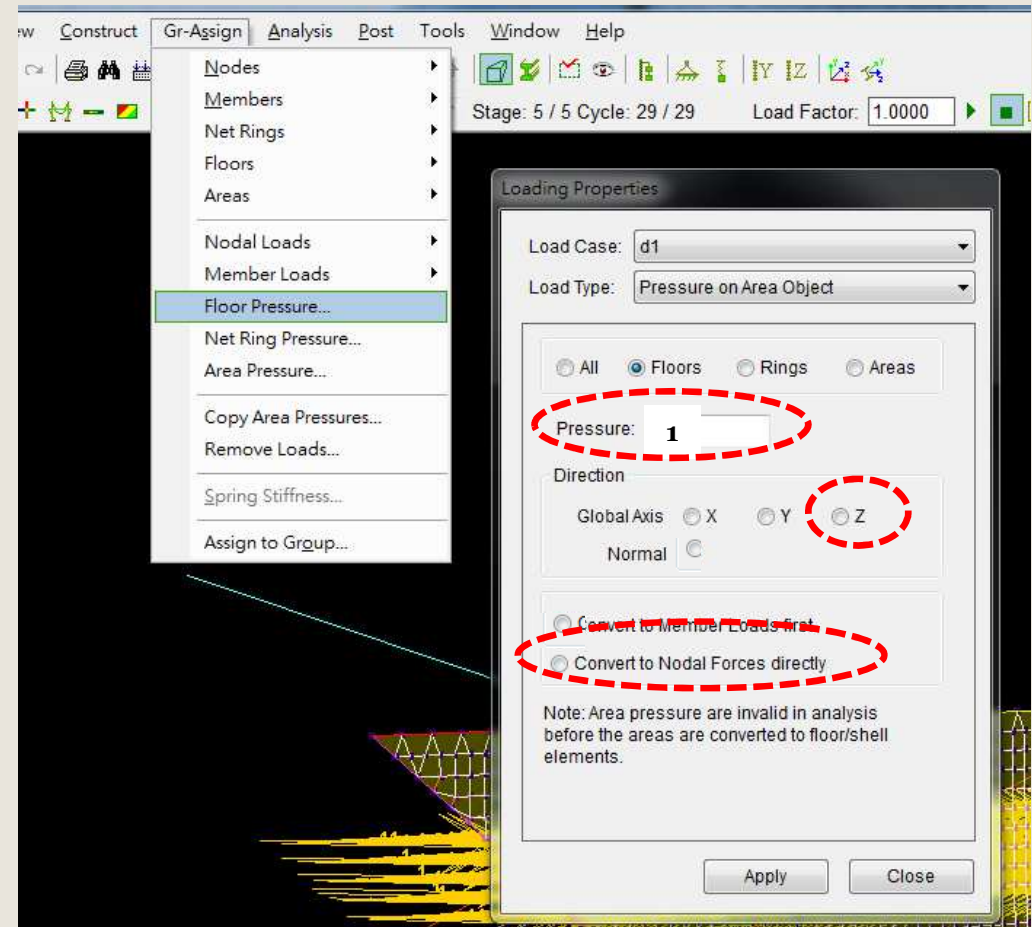
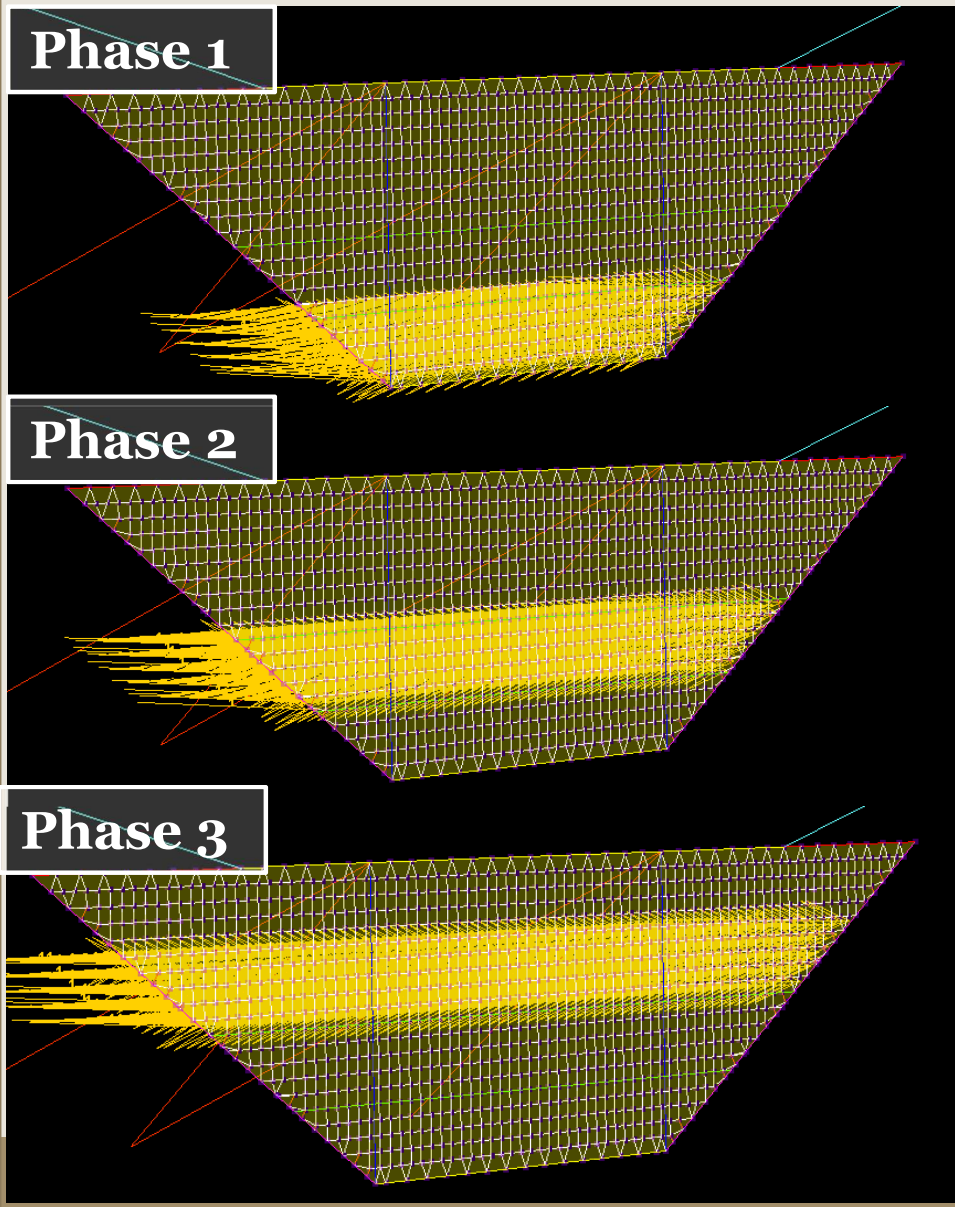


**Cautious about
the normal
direction!**

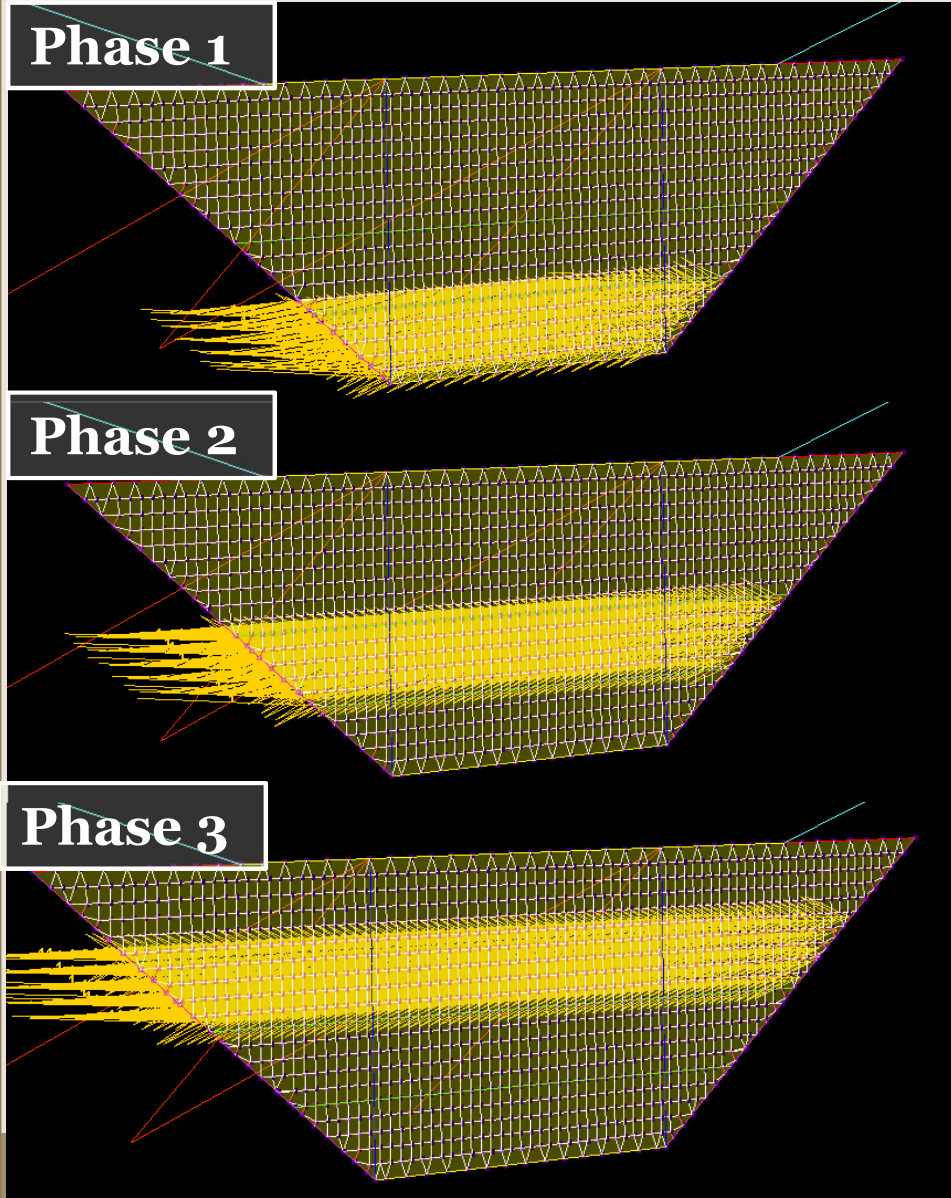
Loading Assignment



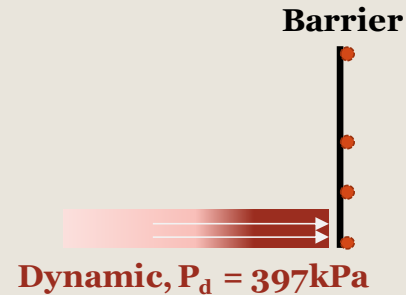
**Only dynamic loadings
are shown!**



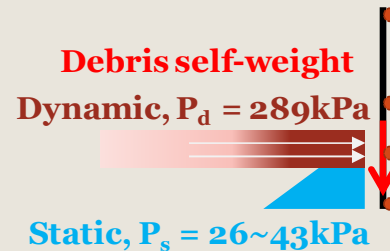
Loading Assignment



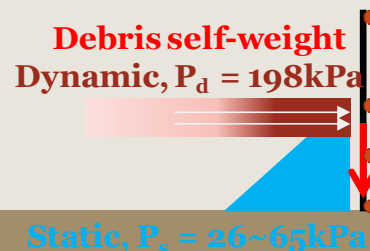
1st Phase



2nd Phase



3rd Phase

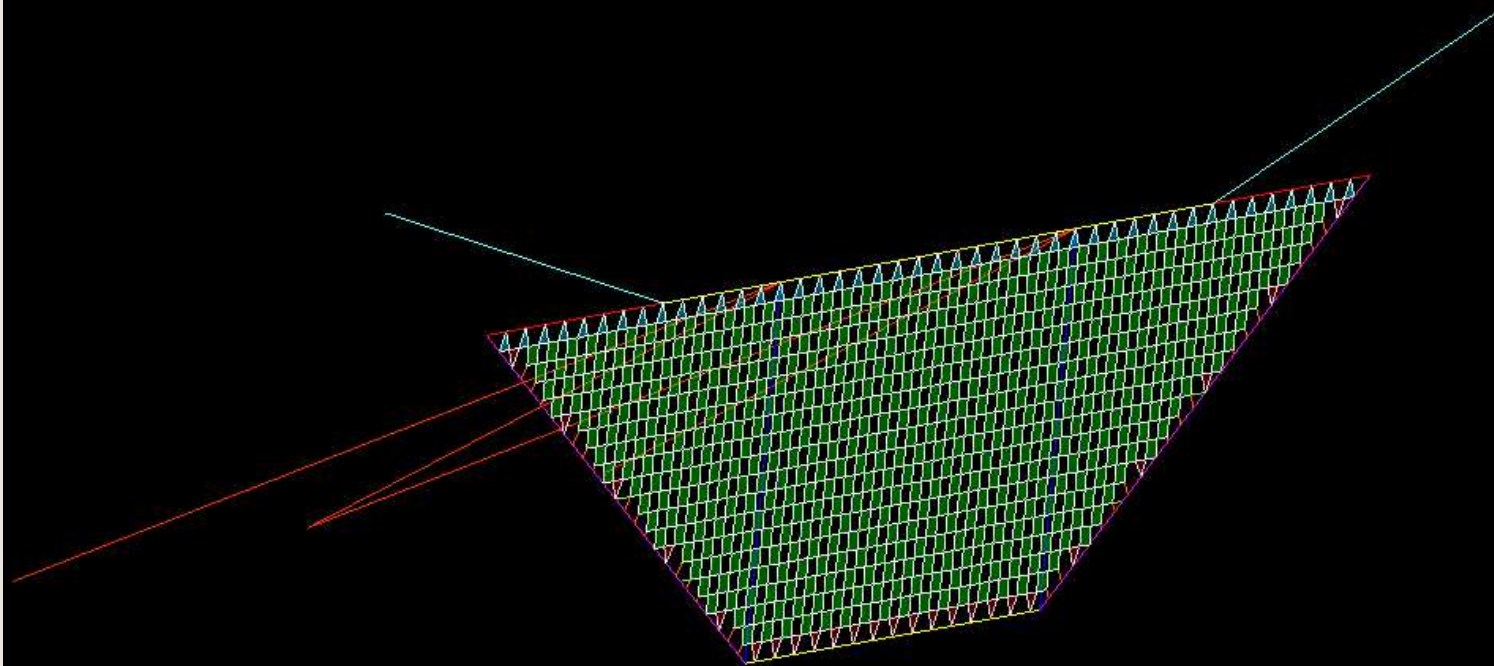


Cautious about the loading - unloading sequence when dynamic load changes to static load!

NIDA-MNN Model



Project: DF7,
Unit: kN, m

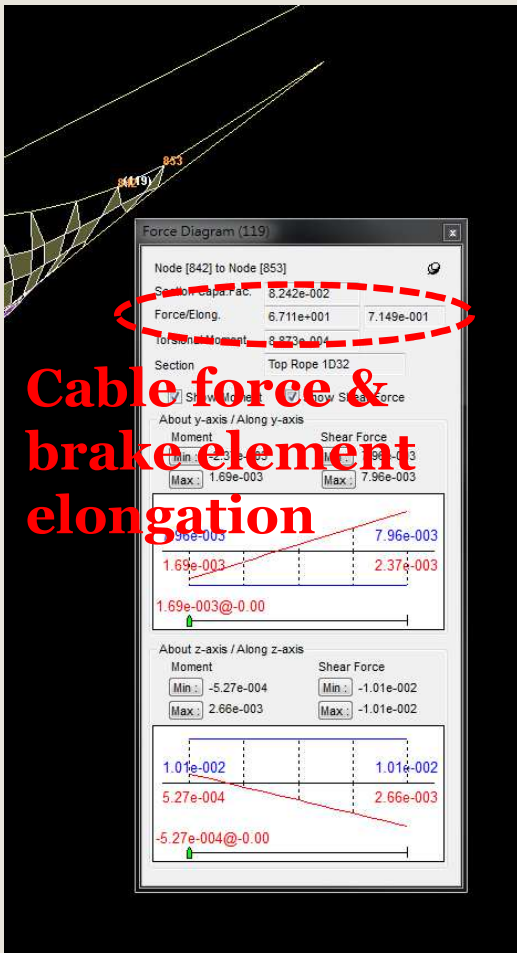


Undeformed

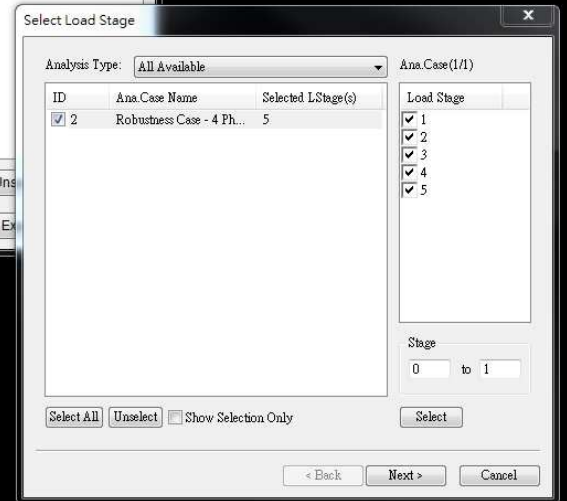
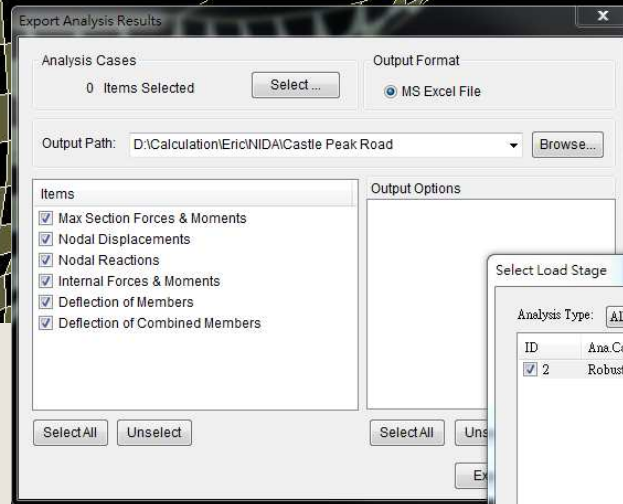
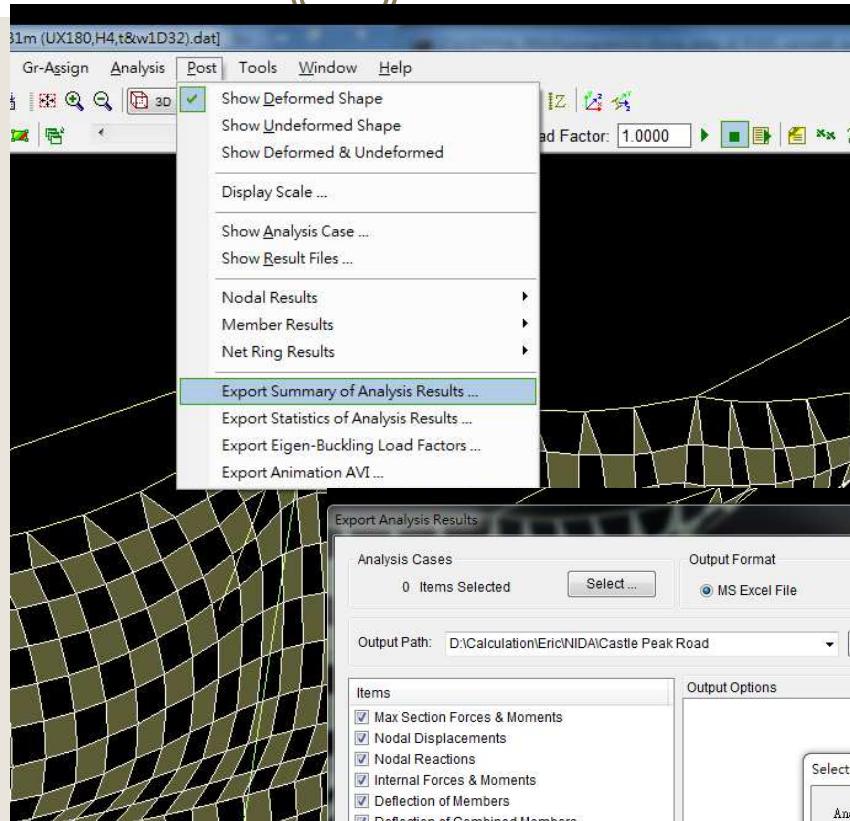
Read the Results

Read results of individual elements at a particular load step

Export the results



Cable force & brake element elongation

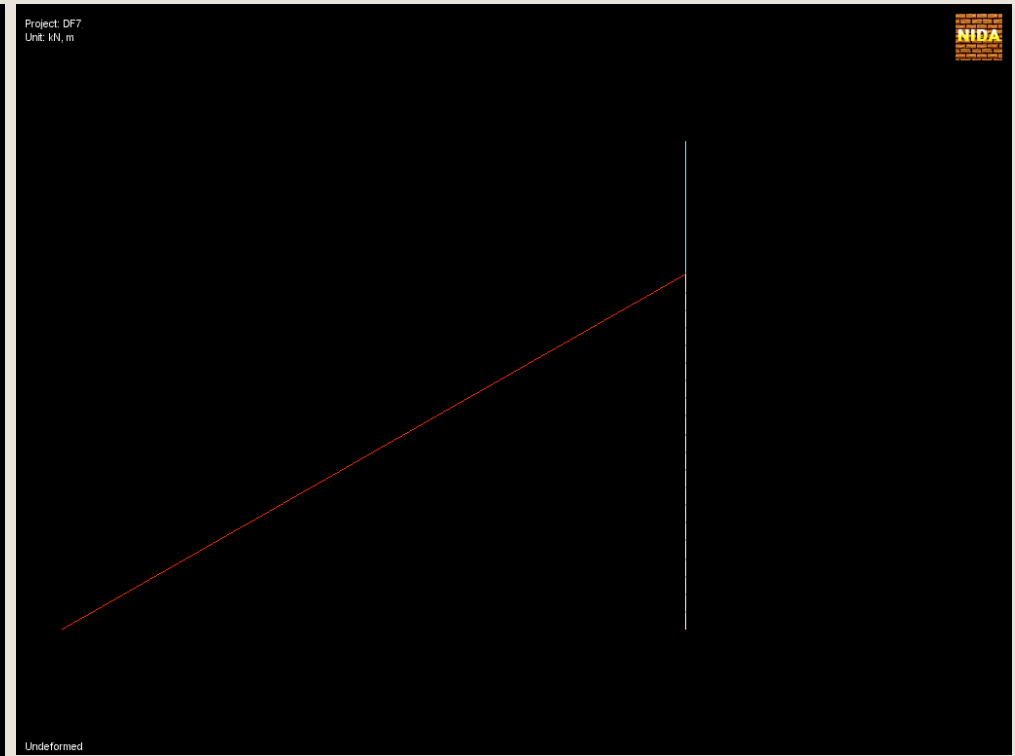
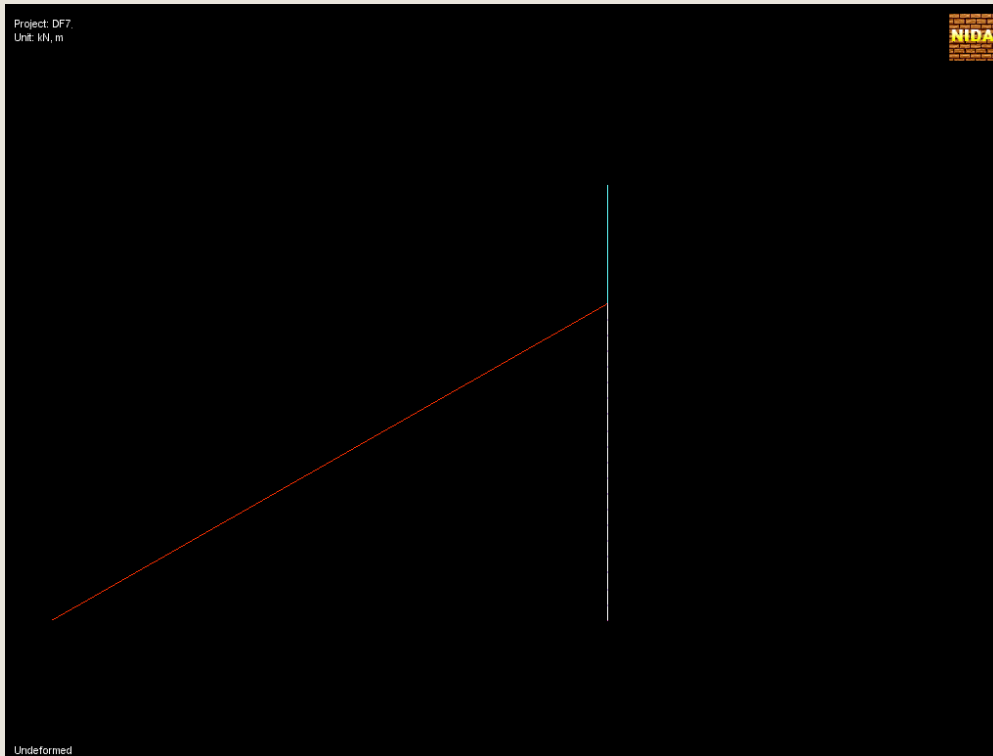


Lower Bound & Upper Bound Brake Element Curves



Lower Bound Brake Element

Upper Bound Brake Element



3. Design Optimisation using Coupled Analysis



Current Design Practice of Barriers

Force approach (GEO DN 1/2012)

$$P = \alpha \rho v_{\max}^2$$

P is pseudo-static impact pressure on barrier

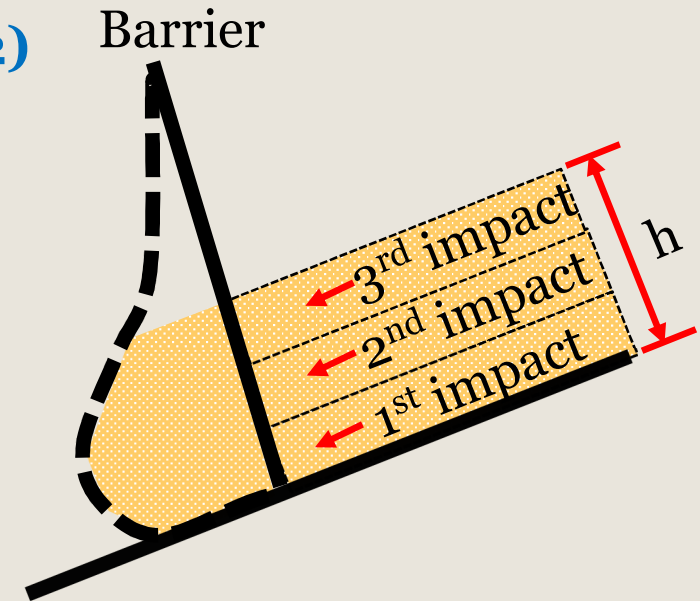
α is empirical hydrodynamic coefficient

(design $\alpha = 2.0$ for flexible barrier)

ρ is density of debris

v is flow impact velocity

h is flow thickness



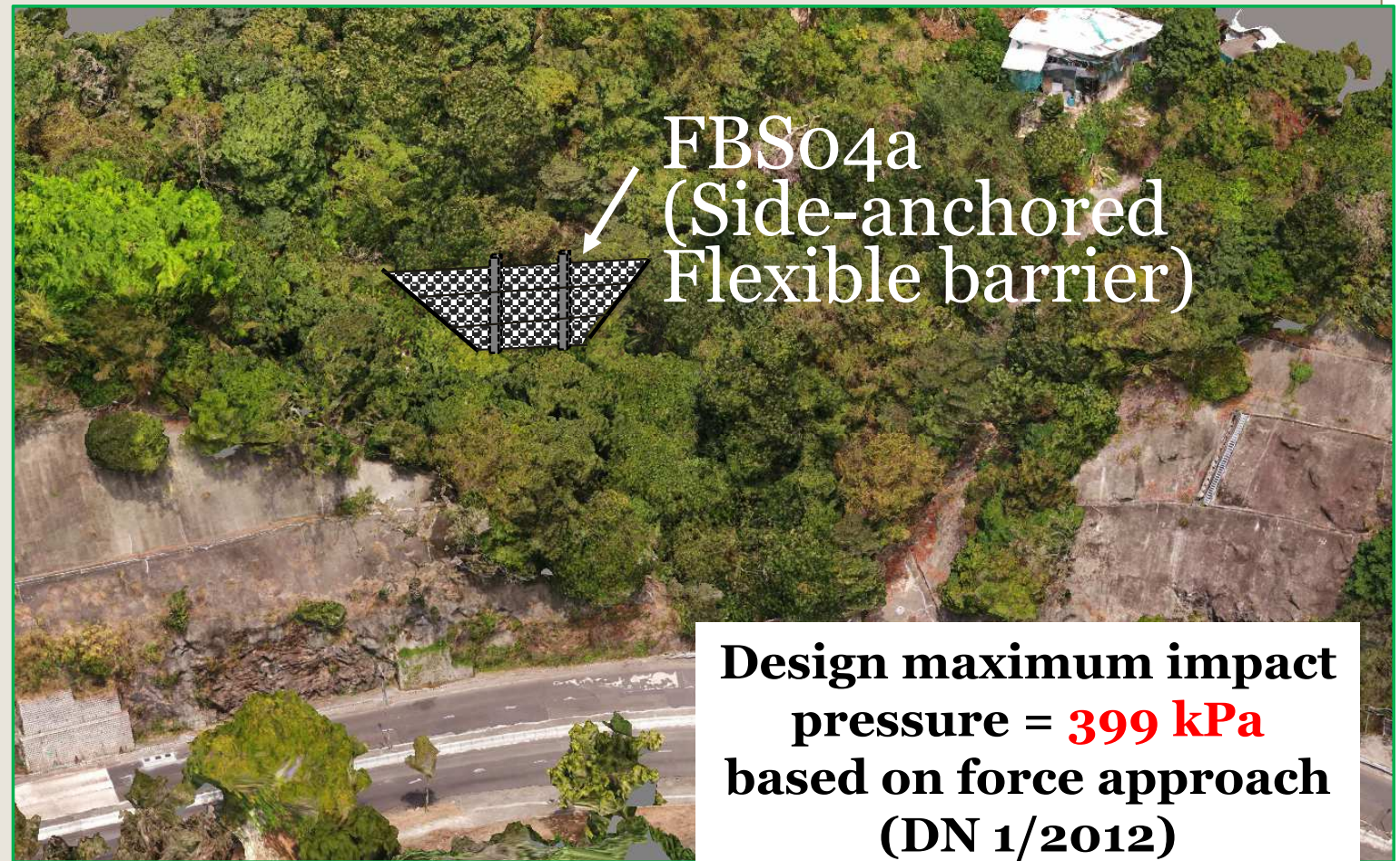
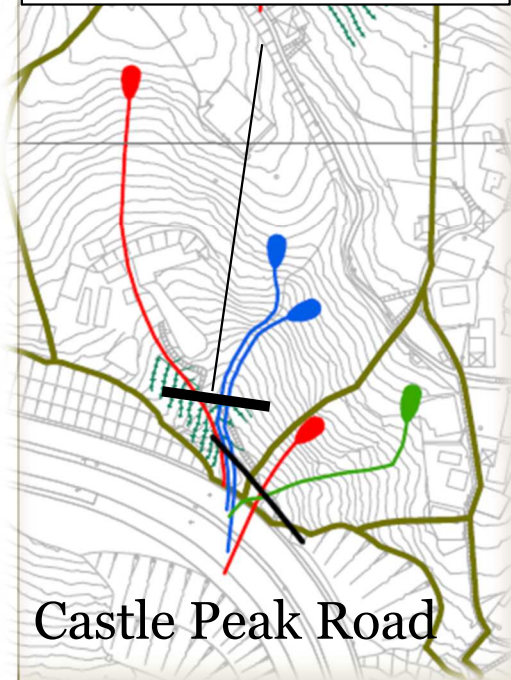
Why we need LS-DYNA?

- *Pseudo-static load \neq Dynamic load*
- *Verify the coefficient “ $\alpha = 2.0$ ” conservative or not*
- *Need a tool for explicit coupled analysis between landslide debris and barriers*

Case Study 1 – Flexible Barrier in Castle Peak Road

Mobility Results

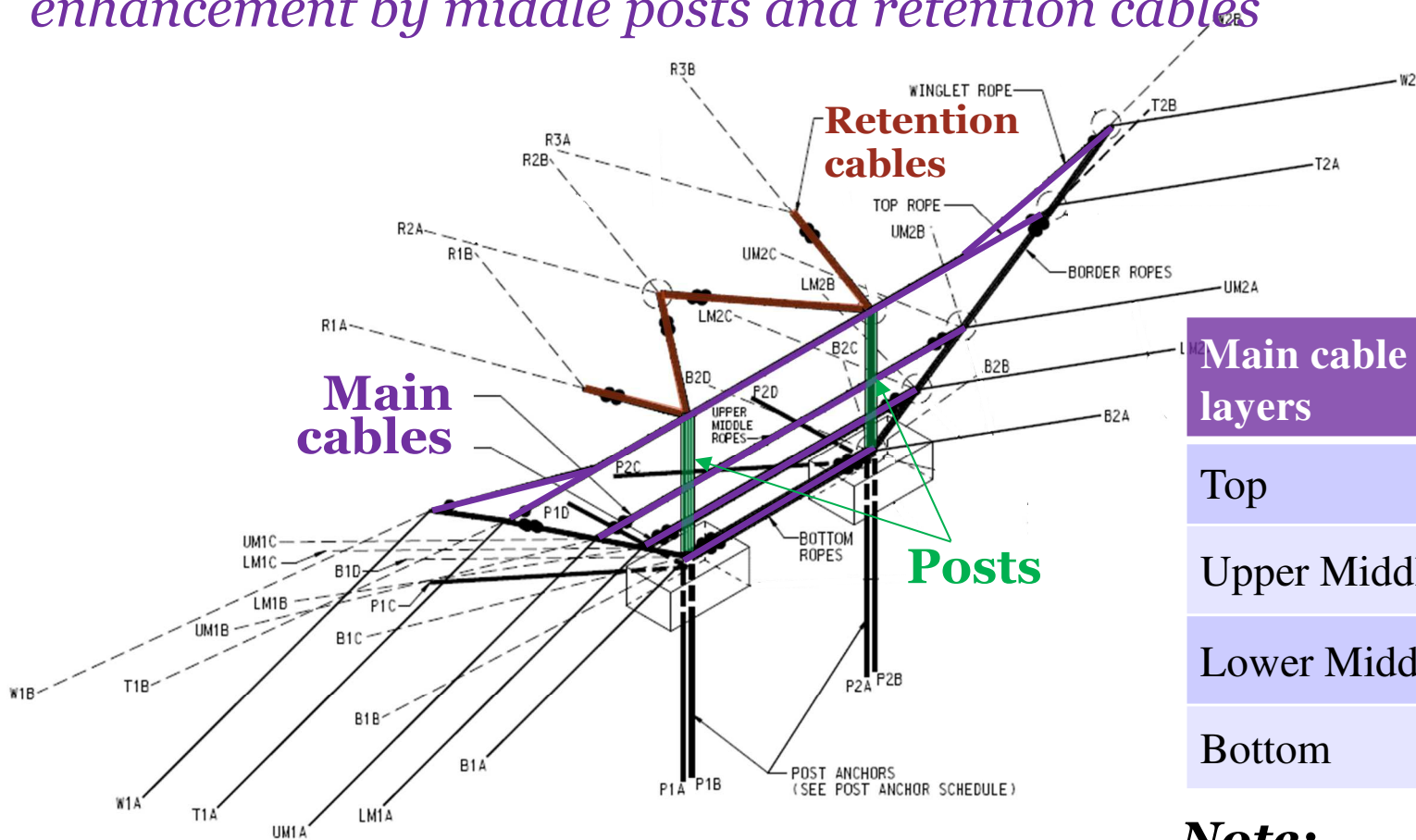
Design Volume = **150 m³**
Impact velocity = **9.5 m/s**
Impact thickness = **1.0 m**
Impact energy > **12,000 kJ**



Design maximum impact
pressure = **399 kPa**
based on force approach
(DN 1/2012)

Barrier Design

Similar to Geobrugg side-anchored UX180 barrier with enhancement by middle posts and retention cables



Main cable layers	Number of cables
Top	1 × 22φ
Upper Middle	2 × 22φ
Lower Middle	3 × 22φ
Bottom	4 × 22φ

Note:
Structural members and details are designed by ASD

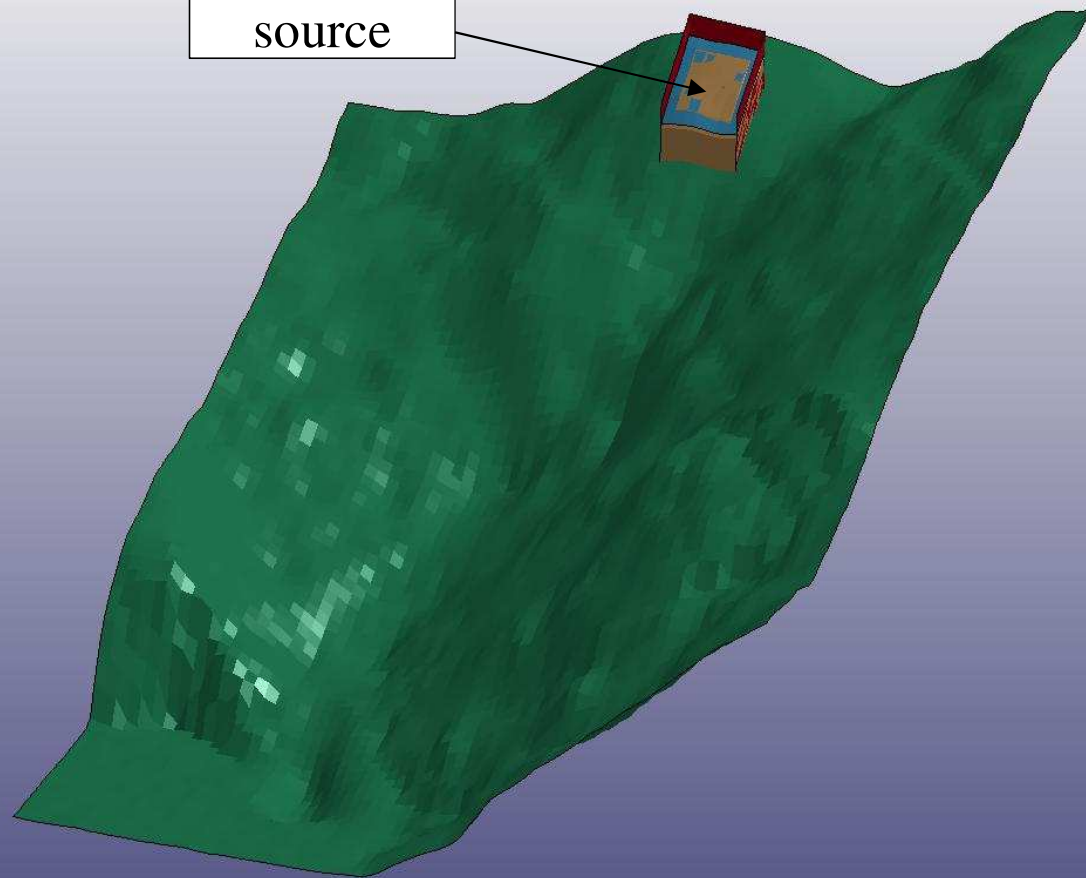
- 5 m tall side-anchored flexible barrier
- Maximum 4 nos. of ground anchors at foundation

Numerical Modelling Using LS-DYNA



LS-DYNA keyword deck by LS-PrePost
Time = 0

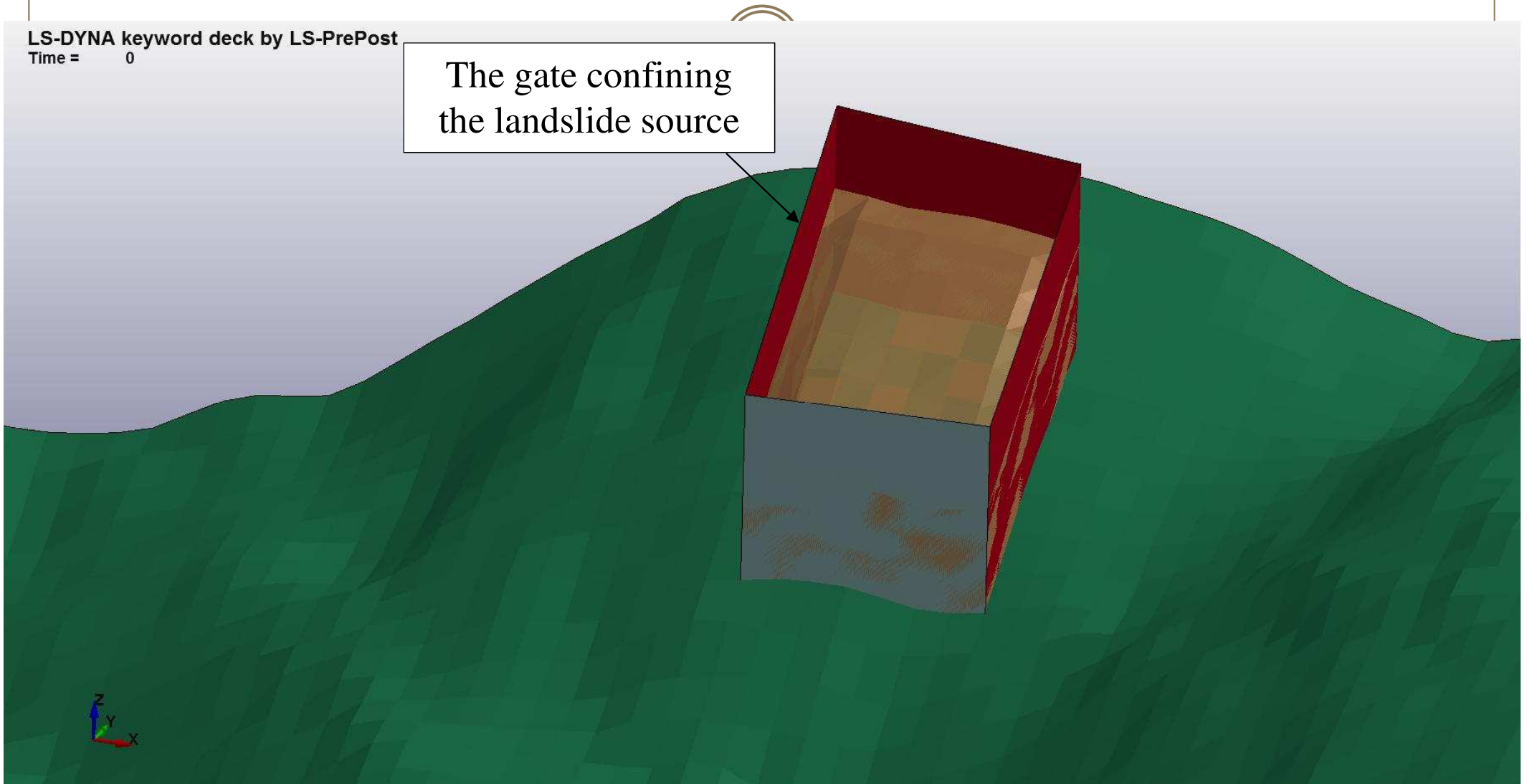
Landslide
source



Numerical Modelling Using LS-DYNA

LS-DYNA keyword deck by LS-PrePost
Time = 0

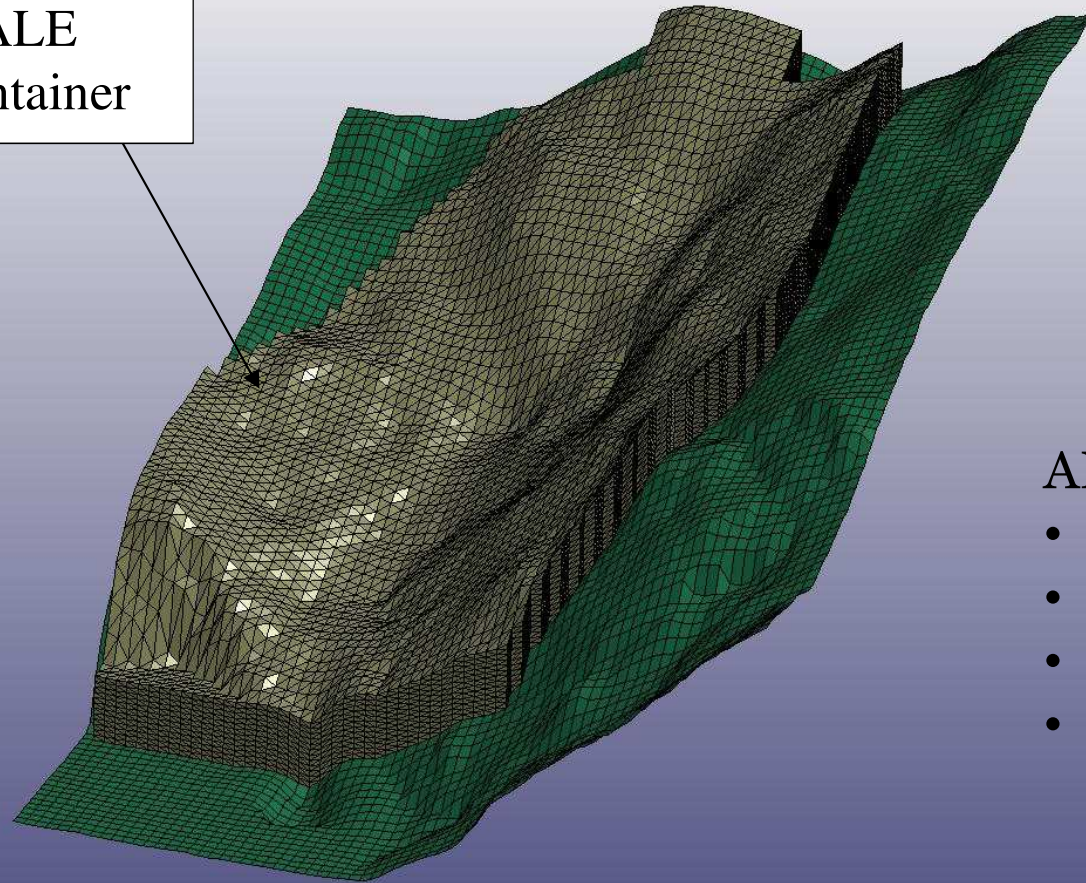
The gate confining
the landslide source



Numerical Modelling Using LS-DYNA

LS-DYNA keyword deck by LS-PrePost
Time = 0

ALE
Container



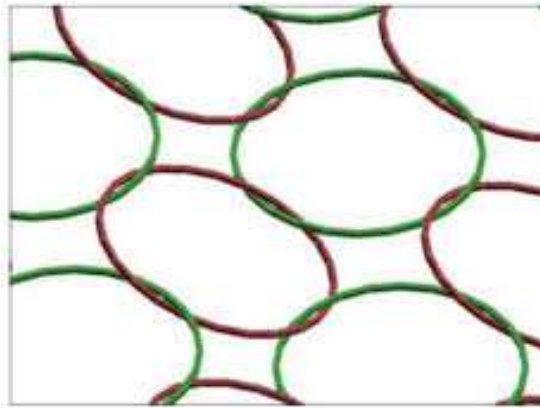
ALE Contrainer:

- Stress
- Strain
- Velocity
- Displacement

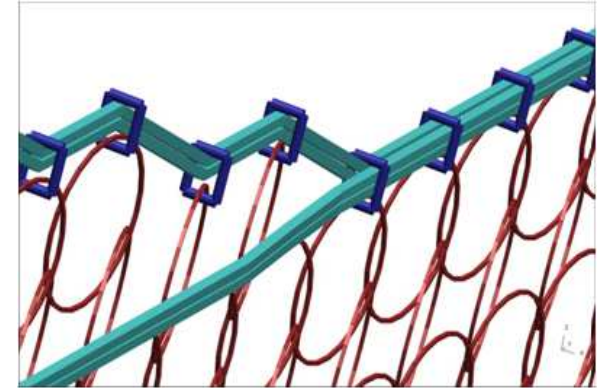
Numerical Modelling Using LS-DYNA

- **Flexible Barrier**

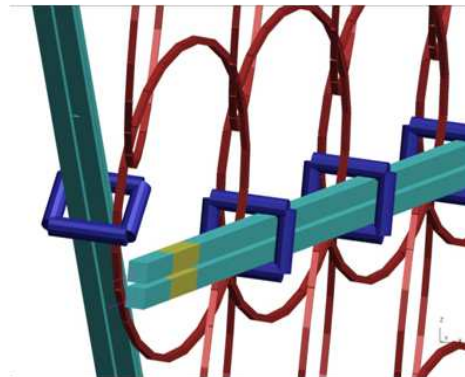
Explicit modelling as elastic beam elements



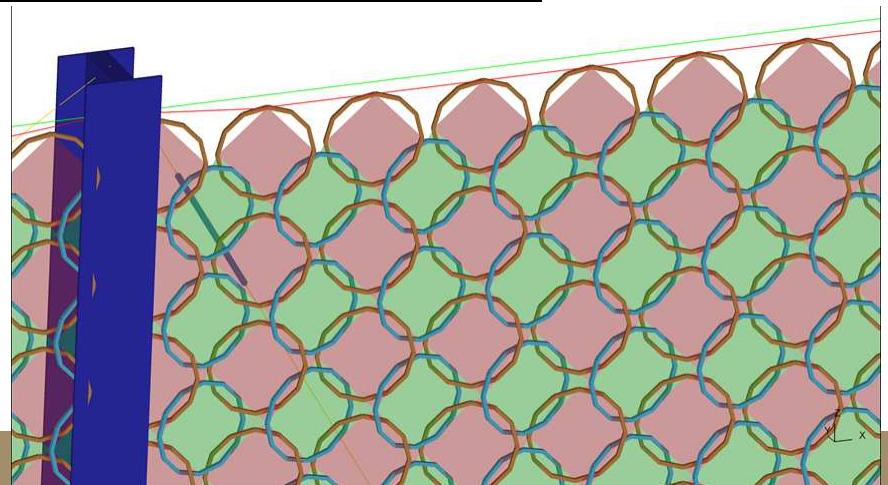
Sliding contacts

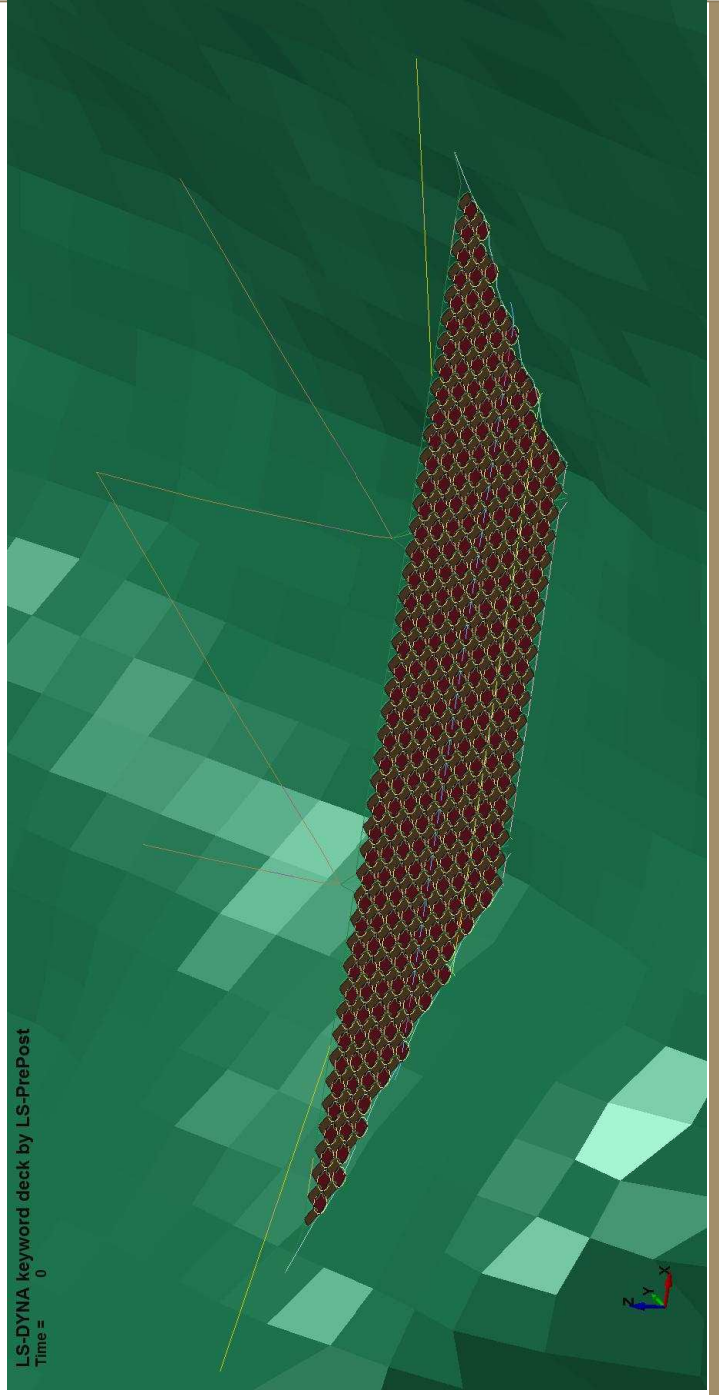
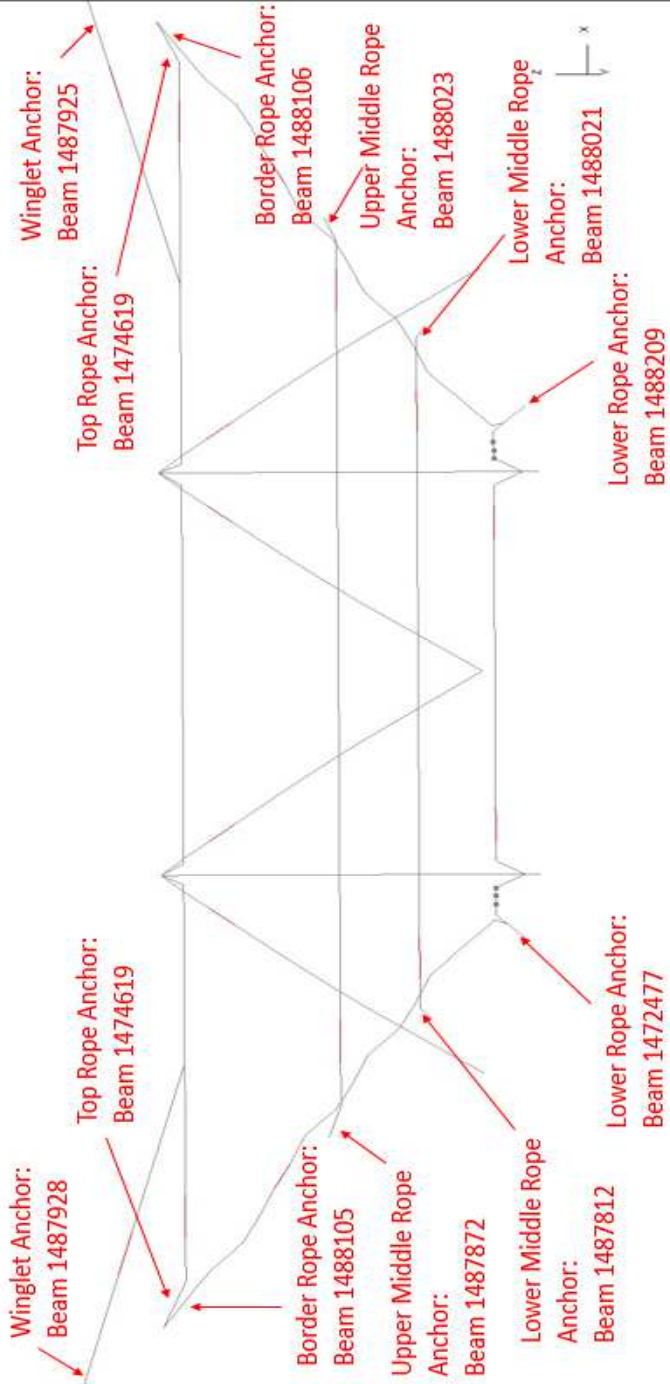


Brake elements



"Null" shell membrane





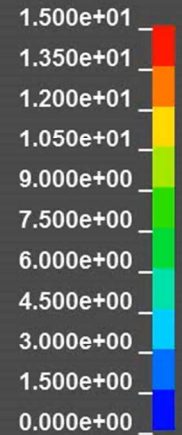
LS-DYNA Simulation

Dynamic Coupled Analysis

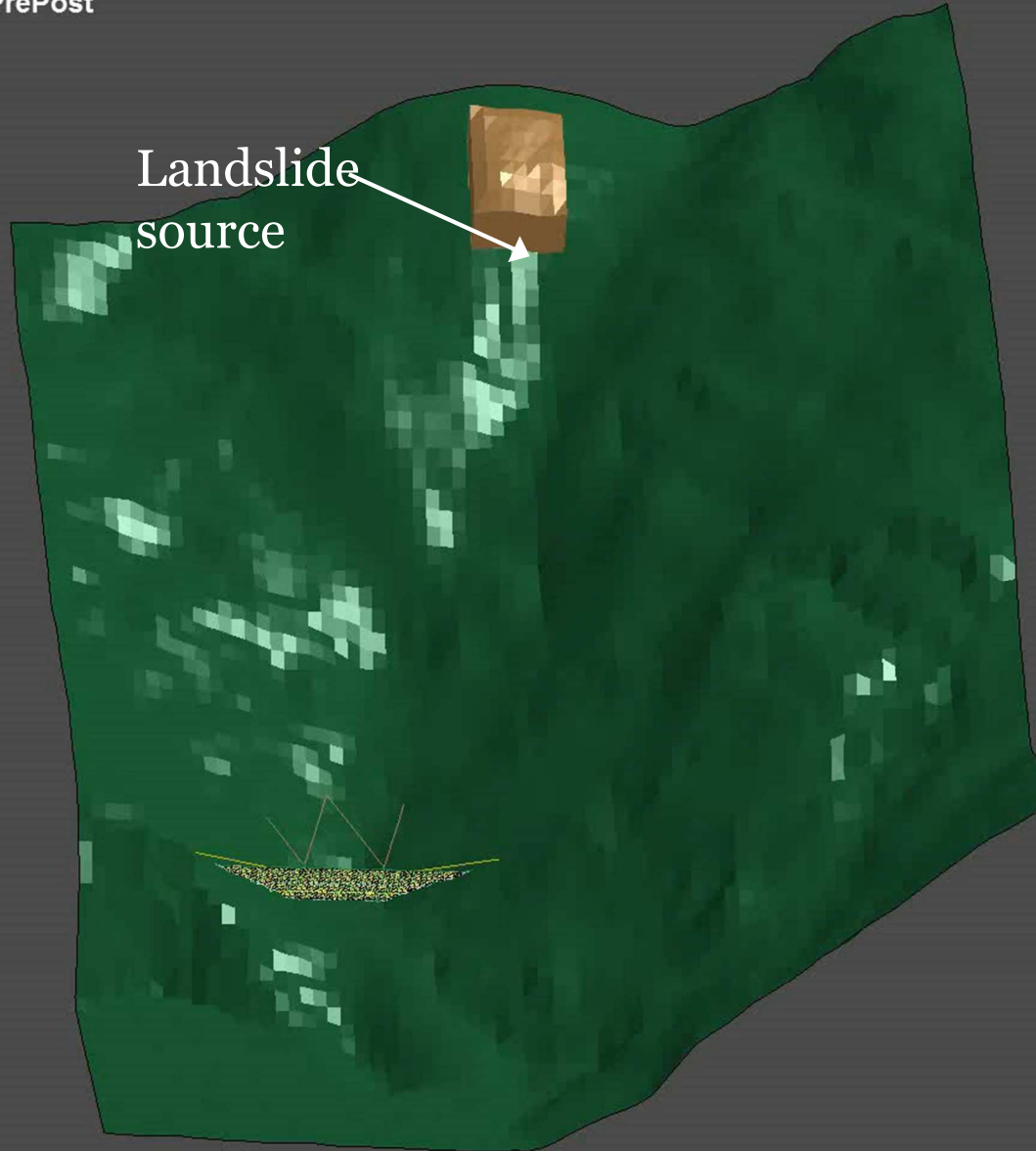
LS-DYNA keyword deck by LS-PrePost

Time = 0
Vectors of Total-velocity
min=0, at node# 2276047
max=0, at node# 2276047

Vectors of Total-velocity



Landslide
source

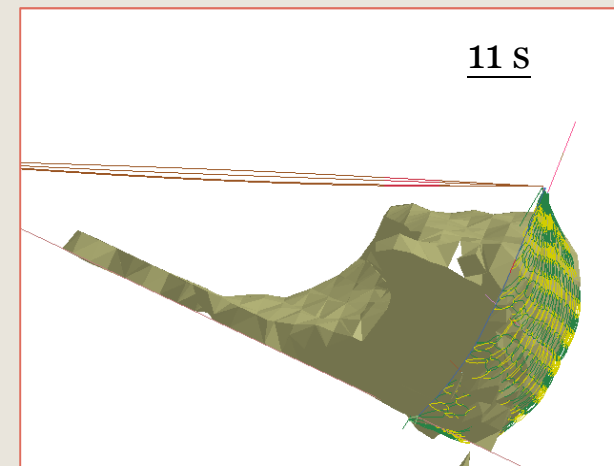
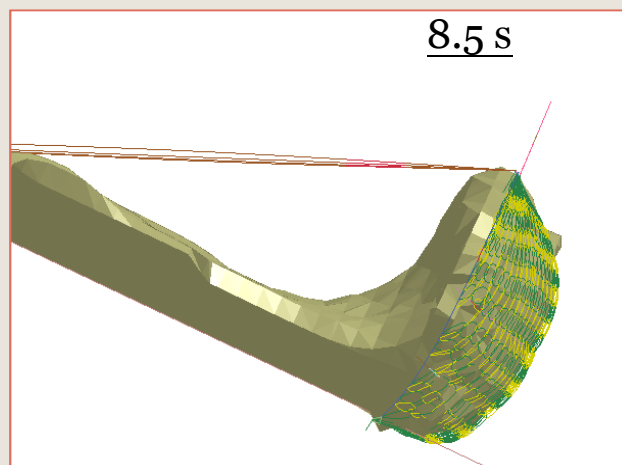
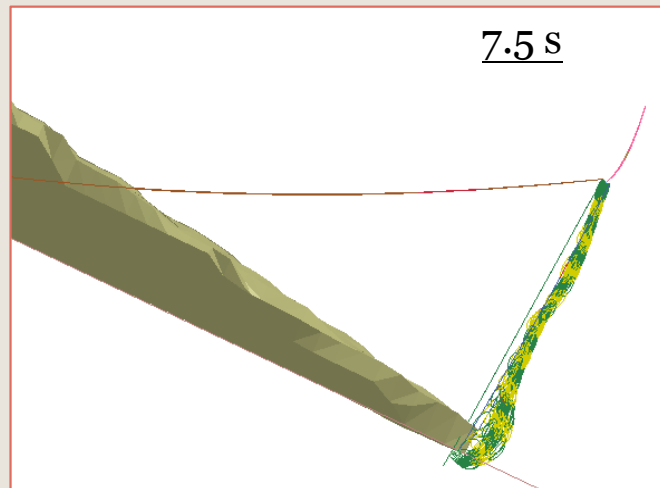


**Coupled
modelling
with debris
mobility and
flexible barrier**

Dynamic Coupled Numerical Simulations

Program LS-DYNA

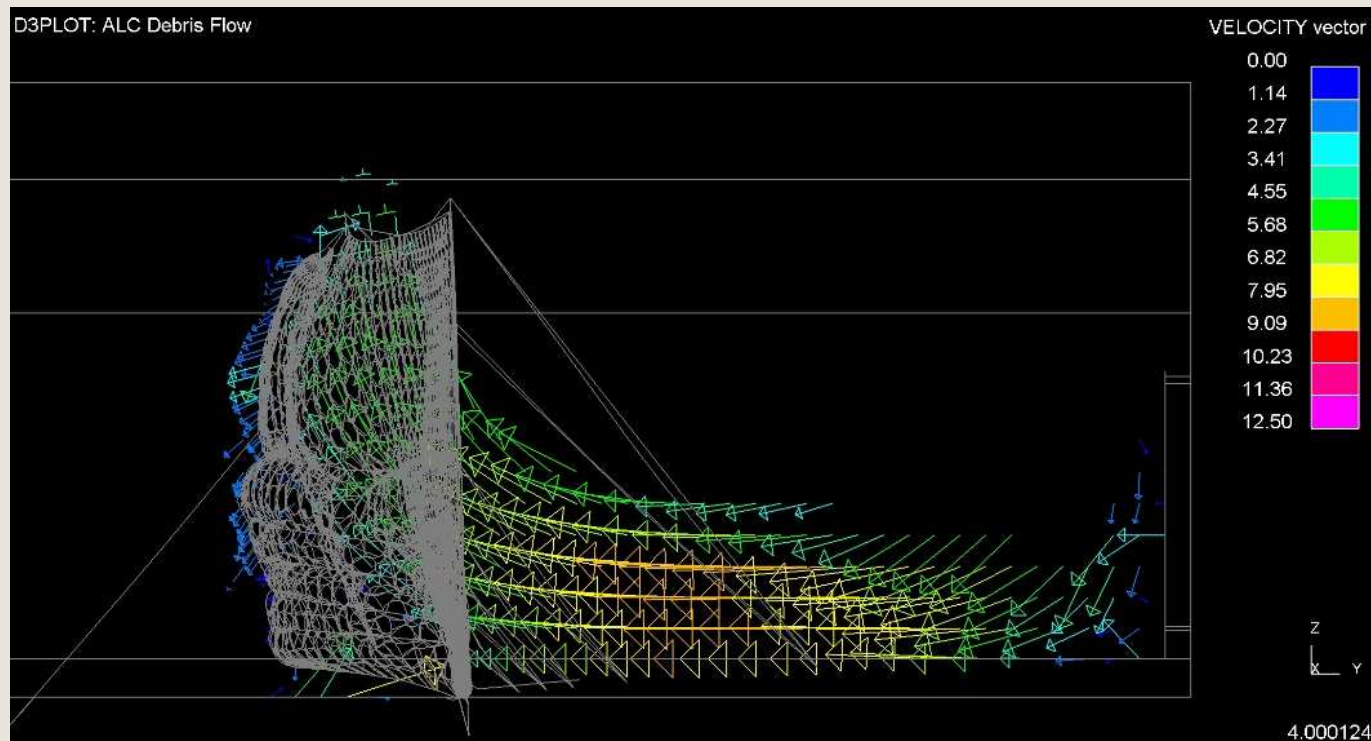
*Observed
pile-up
mechanism
(TN1/2012)*



Debris-barrier Interaction

Coupled analysis approach

- Enhance understanding on the performance of flexible barrier
 - Energy loss of debris internal shearing
 - Redirection of debris impact momentum after impact

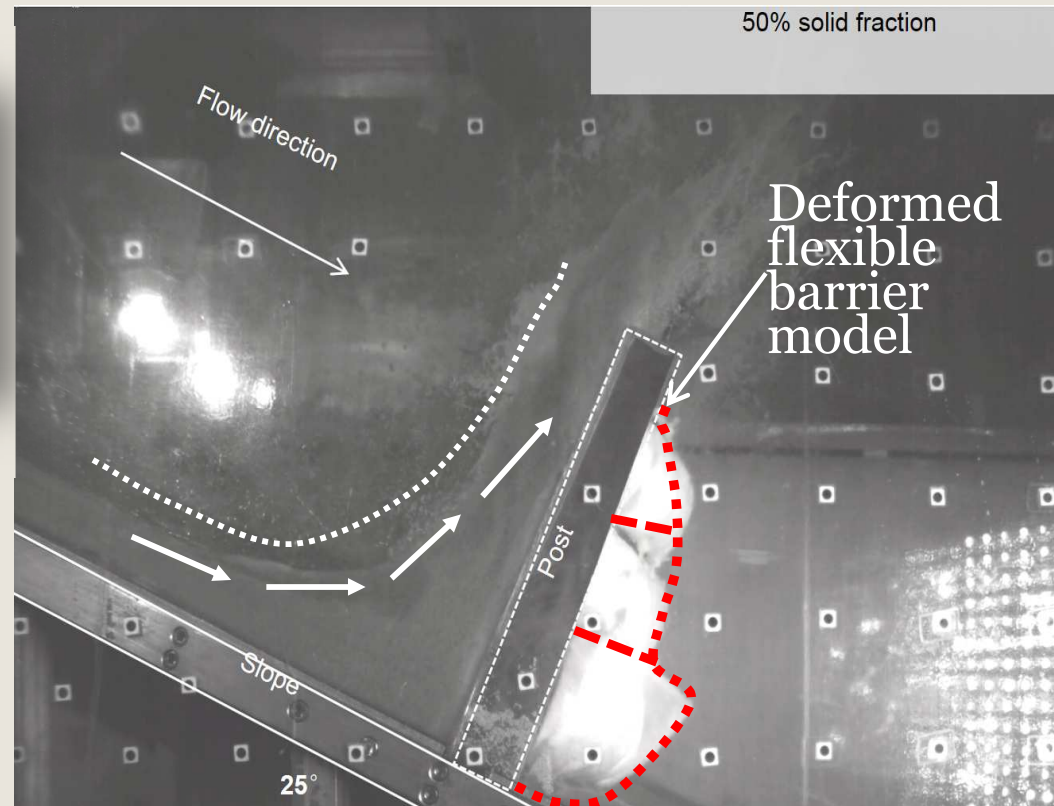


Debris-barrier Interaction

Similar observation from the findings of the centrifuge tests



100 x gravity (g)



Further verification tests to be carried out in large-scale flume by S&T

Kinetic energy is dissipated by redirection of momentum and internal shearing of particles during impact.



THANK YOU