Goa Chapter

Department of Civil Engineering
Indian Institute of Technology Delhi

Development of Large Direct Shear Facility for Geotechnical Characterization and Stability Assessment of Open Mine Dumps

6th Dr Victor de Mello Goa Lecture

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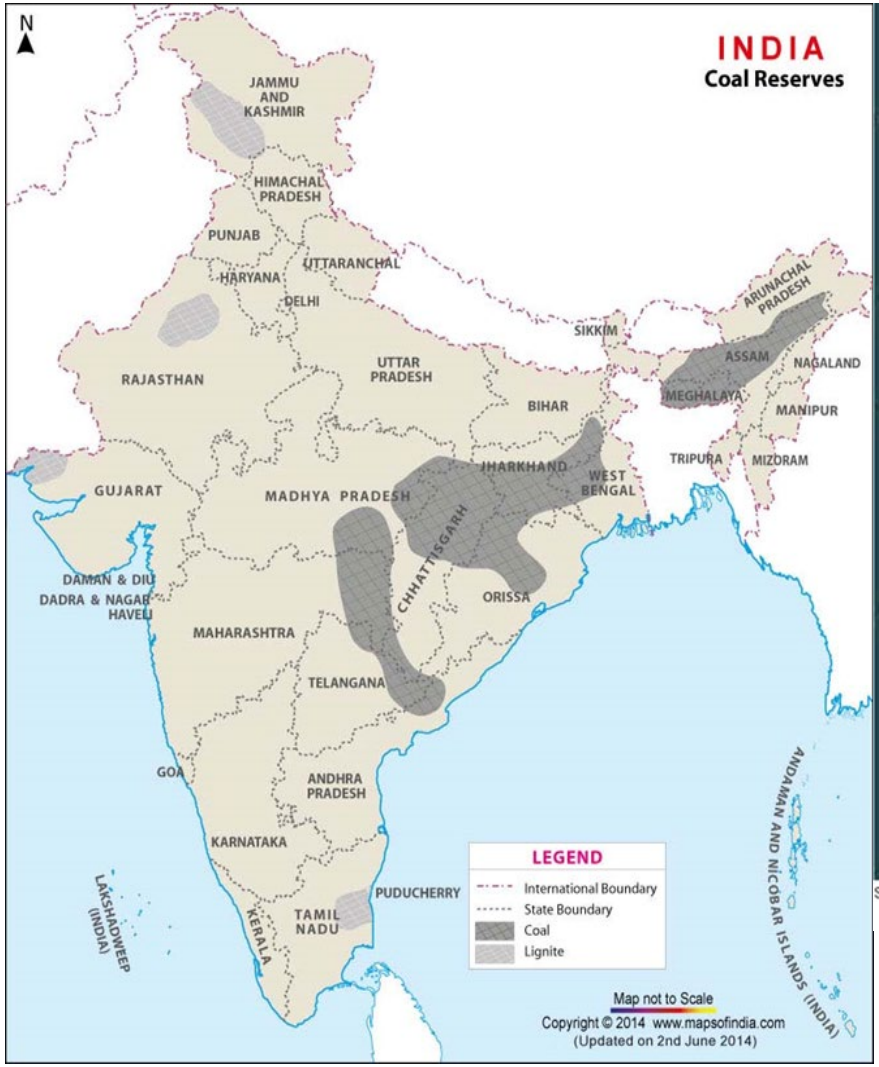
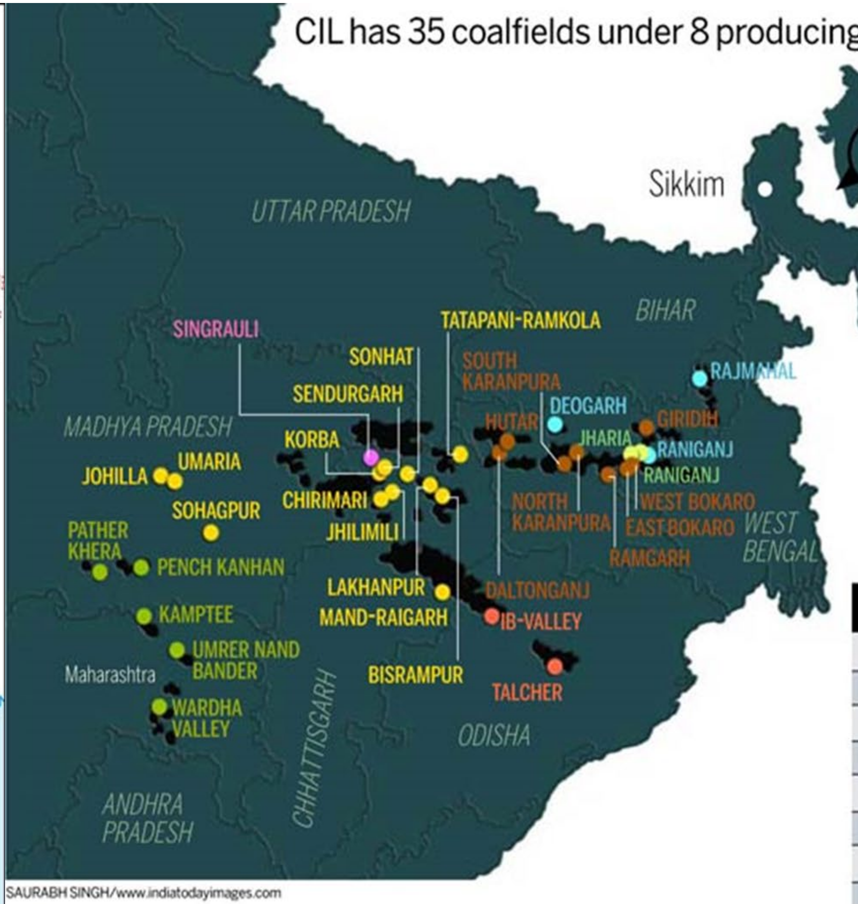
Major Coal Fields in India





Subsidiaries	NO. OF COALFIELDS
Eastern Coalfields Limited, West Bengal	3
Bharat Coking Coal Limited, Jharkhand	2
Central Coalfields Limited, Jharkhand	8
Western Coalfields Limited, Maharashtra	5
South Eastern Coalfields Limited, Chhattisgarh	12
Northern Coalfields Limited, Madhya Pradesh	1
Mahanadi Coalfields Limited, Odisha	2
North Eastern Coalfields, Assam	2

India is the 3rd largest coal producing country after China and USA. CIL-which produces 82% of Coal in India is an apex body with 7 subsidiaries and one mine planning subsidiary (CMPDIL), spread over 8 states of India.

Coal Mining Practices in India

There are two basic methods to extract coal:

- ✓ **Opencast mining**
- ✓ **Underground mining**

A number of alternative technologies are associated with each method.

✓ *Opencast mining* is used when the coal is typically **less than 200 feet** below the surface. Giant machines are used to remove the top layers of soil and rock to expose the coal.

- This method is used most frequently in India because much of the coal resource base is near the surface, and it is less expensive than underground mining

✓ *Underground mining* is used when the coal is **buried several hundred feet below the surface** or more. Some underground mines require elevator shafts to move miners and coal to and from the surface.

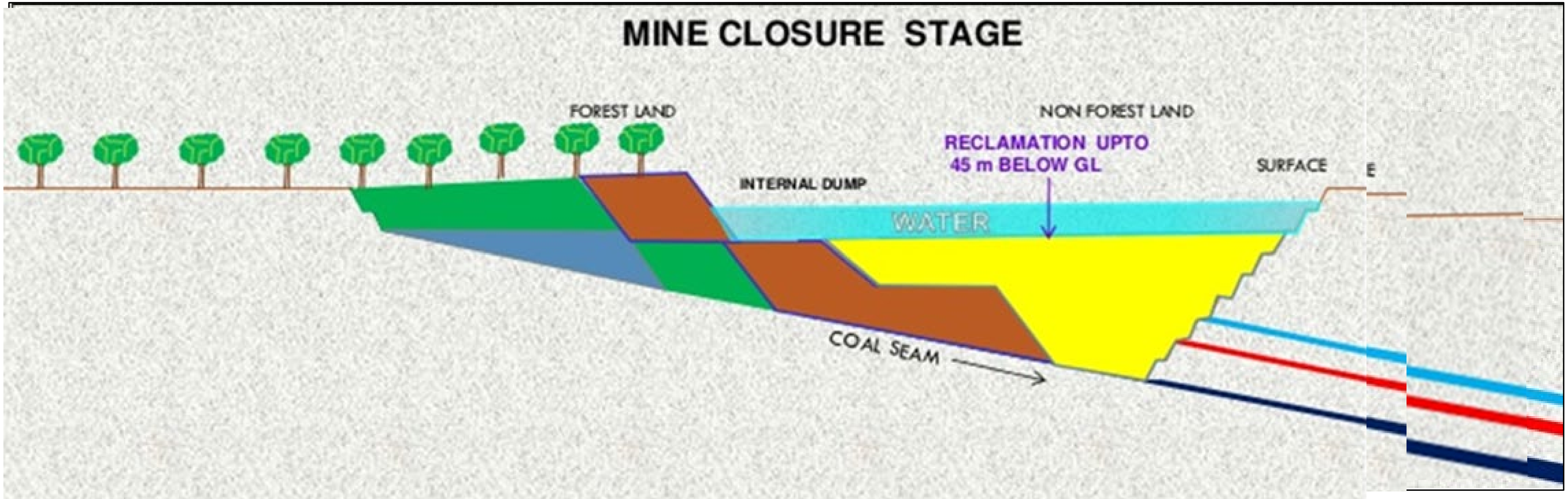
In India 90% of total Coal production is being done under Opencast mining

Open Cast Mining of Coal

Stage -1: Project Area: Comprises of Forest and Non-Forest Land.

Stage-2 :Removal of Overburden to Expose Coal Seam.

Stage-3 : Sequence of Benching –Subsequent Internal Dumping.



Stge-4 : Further Excavation to Achieve more Coal.

Stge-5 : Final Stage of Excavation.

Stge-6 : Technical and Biological Reclamation.

Major Coal Fields in India

- ✓In recent years the unprecedented increase in the rate of accumulation of waste overburden dumps has been a great geo-environmental concern mainly because of frequent dump slope failures

- ✓As the production from the **opencast mine is going up at higher stripping ratio**, the problems of over burden dumps and accommodation thereof have posed another challenge, that need immediate attention.

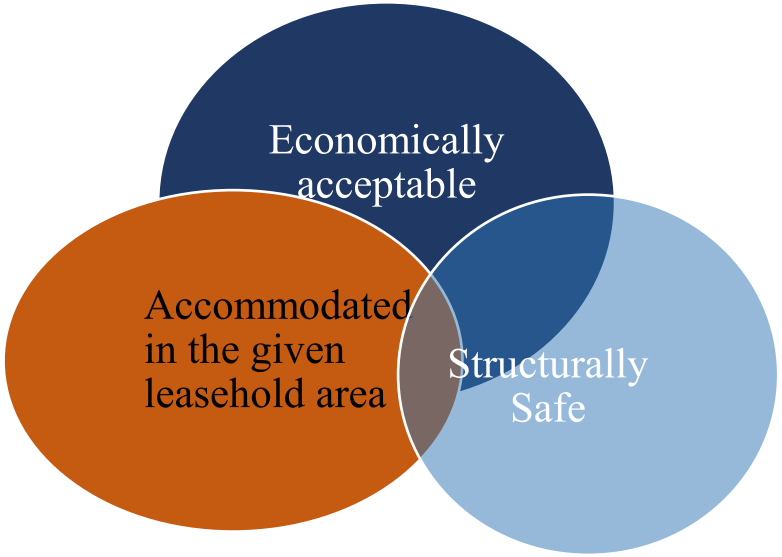
- ✓It is, therefore, a great techno- economic and operational challenge to go for the most efficient design, in the light of **two conflicting requirements by optimizing the dump slope angle that is steep enough to be economically acceptable and flat enough to be safe.**

- ✓**Optimum stable dump slope dimensions during and after mining operations are the industry requirements worldwide.**

Major Coal Fields in India

Flatter Slopes → Better Stability → Requires Large area of Land → Permanent locking up of huge quantity of coal resources → Steeper slopes → Increases potential failures

What we need ? A Slope



Geotechnical characterization

Test of representative samples under field scale stresses (LDSTM*)

*Large Direct Shear Testing Machine

The interactions between fragmented rock and loose soil particles, and their size distribution in overburden dumps are very important components of the know-how from the Engineering perspective

Testing Approaches

Current knowledge of mine overburden shear strength behavior falls well short of that of soil mechanics for several reasons.

- ✓ **Conventional laboratory-scale testing and engineering judgment** : A shortcoming to the conventional testing is that oversize particles are usually scalped to accommodate the device capacity. Therefore, the influence of prototype-size particles on the geotechnical behavior of mine overburden is not truly captured.

- ✓ **No significant analyses of the effect of dynamic loading impacts** : At present only static loading conditions are being considered in determining Strength properties of overburden. This undermines the effect of HEMM/Blasting, seismic effects in the OB dump Design.

- ✓ **Representative overburden samples at field stress conditions are not analyzed** : For testing coarse materials such as overburden, a direct shear box capable of handling larger samples (300 mm x 300 mm) is becoming common-place in geotechnical laboratories and can test coarse gravels at normal stresses up to 1 MPa. However, this is still not of sufficient size to handle the cobble and boulder size particles typical of coal mine spoil.

This leads to overestimation of Shear Strength of OB material triggering, Slope Stability problems in Opencast Mines

Types of Over-Burden (OB) Dumps

✓Internal dumps minimize re-handling of OB material and are efficient in utilization of available land.

✓However, dump failure can halt mining operations, endanger personnel and damage equipment

✓External OB dumps may be less efficient in material handling and land use

- However, they reduce consequences to mine operations in the event of dump failure although external dump failure may have greater social and environmental consequences.

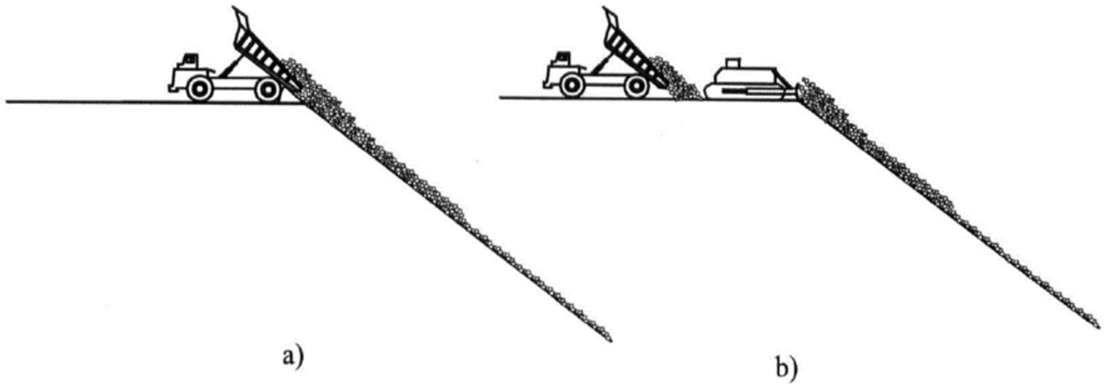
- The combination of external dumps and internal dumps shall substantially reduce the required land. As a result, it shall reduce the surface land requirement significantly due to the growth of population, forest cover and associated problem

Types of Dumping

Based on material dumping, dumps can be classified as:

- ✓*End dumping* - dumping material over dump face resulting in some particle size segregation down slope towards the toe of the dump, with particle size generally increasing.
- ✓*Push dumping* - dumping from trucks, followed by leveling and pushing by tractors and shovels resulting in particle size segregation: finer at the top and coarser at the toe of the dump slope.

End Dumping



a) End dumping

b) Push dumping

Different Elements at Lakhanpur Opencast Project

Typical composition of OB materials

Angle of Repose -Section of External Dump at Nigahi OCP

Rajmahal OCP -ECL

OB dump failure at Rajmahal OCP , MCL

At the time of accident, while operation of OB removal is going on by excavators and tippers, a large area (600m×100m) slided down by 30m due to which 12 of the 30 deployed tippers and 5 excavators along with the operators got trapped by the sliding material.

Total fatalities: 23

View from top of the failed Dump and opposite side

OB dump failure at Bharatpur OCP , MCL

Need for the Study

- ✓ To meet targeted one-Billion-ton Coal production by 2025, India will have to go deeper for coal extraction. With **estimated average stripping ratio of 2.75**, there will be a need to handle 2.75 Billion cum of Over Burden (OB).
- ✓ It is also required to render the **post-mining landform into a stable and environmentally sustainable one**.
- ✓ Experimental and Analytical approaches are necessary to ensure safety and stability of the dump sites.

✓ Stripping Ratios

✓2020-21	1244.731(M.Cum)	569.768 (MT)	2.18(SR)
✓2021-22	1335.59 (M.Cum)	597.008 (MT)	2.24(SR)
✓2022-23	1646.57 (M.Cum)	677.71 (MT)	2.43(SR)

Scope of the Study

✓From the view of:

- Increasing rates of Overburden generation in opencast mines.
- Increasing pressure on the existing land to receive Overburden beyond initially designed geometry.
- Demand for reclamation of the abandoned land/mined out areas.

✓The stability analyses of Overburden dumps need to be evaluated under static and dynamic loading conditions.

✓A simple destabilization of the dump slopes will eventually damage the integrity. of mine components and may lead to loss of life and property.

Issues with Current Design Methods

✓ Conventional laboratory-scale testing and Engineering judgment : A shortcoming to the conventional testing is that oversize particles are usually scalped to accommodate the device capacity. Therefore, the influence of prototype-size particles on the geotechnical behavior of mine overburden is not truly captured.

Current knowledge of mine overburden shear strength behavior falls well short of that of Soil Mechanics for several reasons

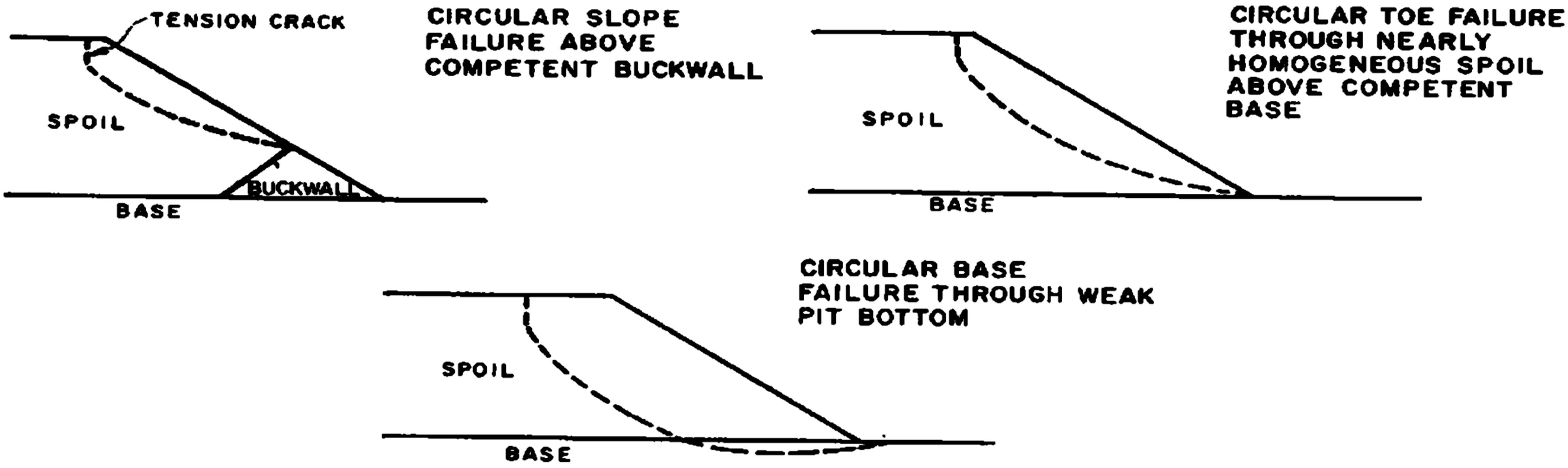
Issues with current design methods

✓ Representative overburden samples at field stress conditions are not analyzed: For testing coarse materials such as overburden, a direct shear box capable of handling larger samples (i.e., 300mm×300mm) is becoming common-place in geotechnical laboratories and can test coarse gravels at normal stresses up to 1 MPa. However, this is still not of sufficient size to handle the cobble and boulder size particles typical of coal mine OB.

This leads to not exact understanding of Shear strength of OB material triggering Slope Stability problems in Opencast Mines.

Failure Mechanisms

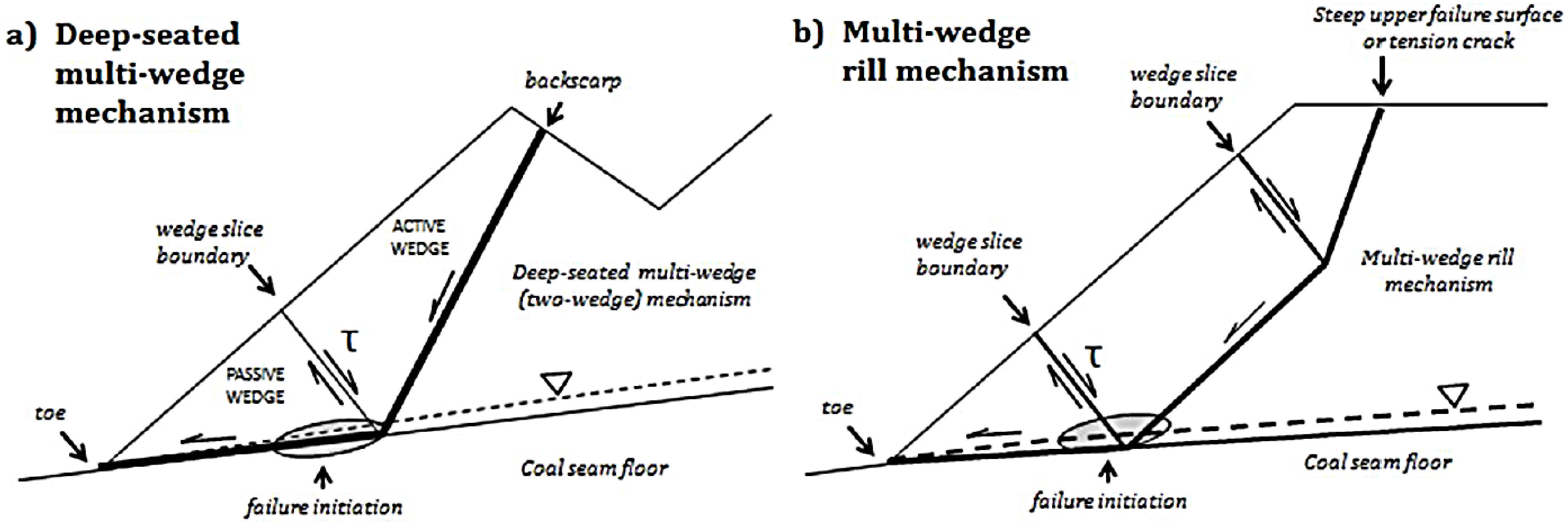
Shearing Behavior of Coal Mine OB Dumps:



Types of Circular Failures (Rizkalla, 1983)

Deep Seated Failure Mechanisms

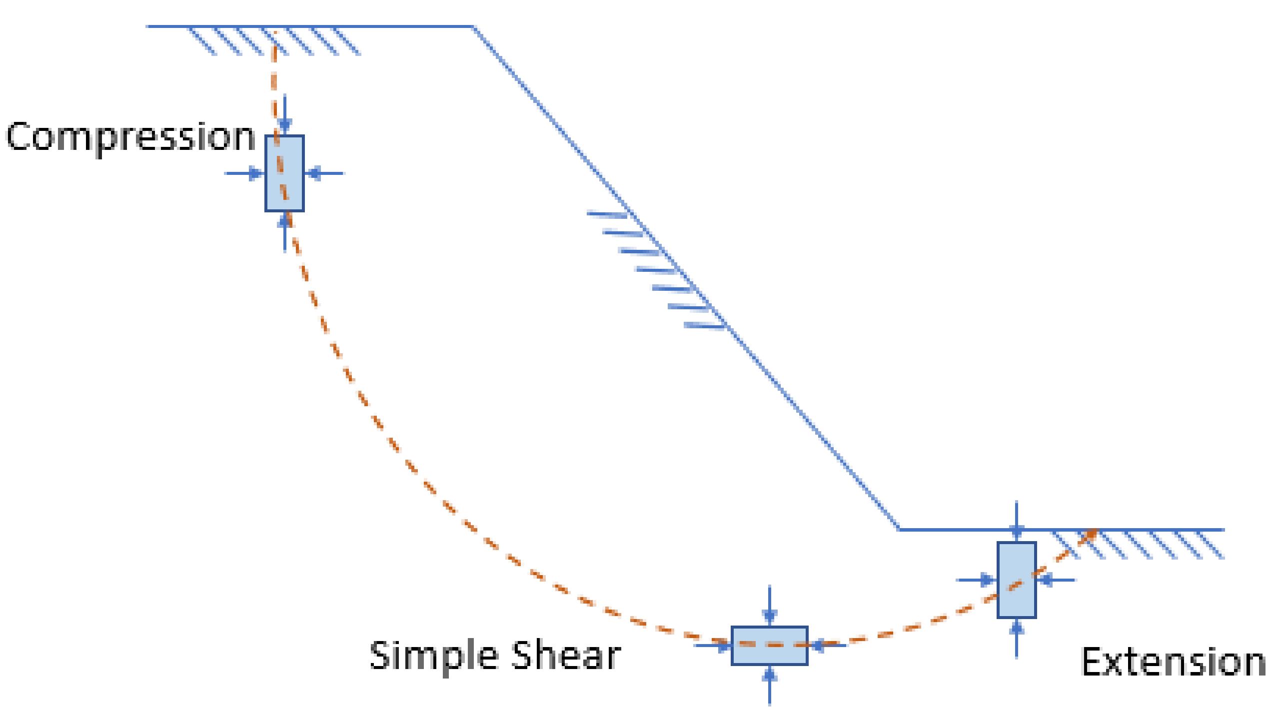
Shearing Behavior of Coal Mine OB Dumps:



Deep-seated multi-wedge failure mechanism (Simmons and McManus, 2004)

Stress Path to Failure and Significance of Test Apparatus

To simulate drained over burden (OB) dump failure in the laboratory, shear strength parameters could be determined from triaxial or direct shear tests.



Scale Effects

- ✓ OB dumps commonly **exceed 250m high**. In future, more than 400m .
- ✓ **Scale effect on shear strength** suggests that
  - A minimum test specimen size, and
  - A minimum test normal stress

  that is technically acceptable for simulating a shear failure surface within a high dump constructed of mine materials.
- ✓ **Uncertainty regarding the significance of scale effects.**
  - Practicing engineers are reluctant to apply shear strength parameters determined from Standard laboratory.

How do we determine shear strength for modelling the stability of High dumps?

Scale Effects

1. **Does Particle Size of Coal Dump Material Matters?**

   To what degree can the grading of a OB sample be down-scaled to comply with device limitations, so that the influence of prototype- sized particles on shear strength is not anomalous?

2. **Does Stress Range on Dumps Matters?**

   Normal stress limits of test apparatus. Can the failure envelope developed from small-scale tests be reliably extrapolated out to the much higher stress ranges to simulate field conditions for dumps of modern and future heights (>350m) ?

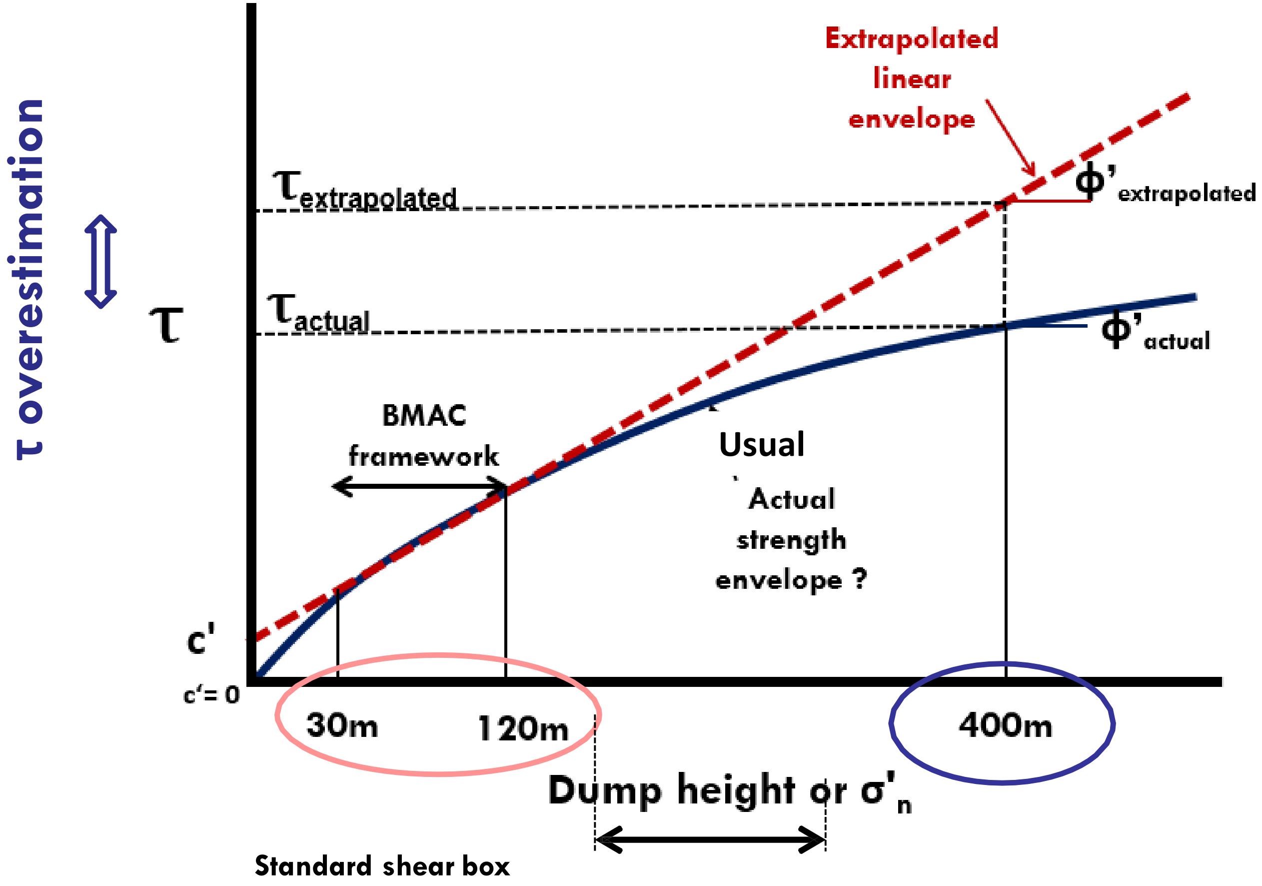
Dump Height

Spoil dumps rarely exceeded 90m in height
Max $\sigma_n \leq 1MPa$

Dump Height

Fast forward to dumps of modern times High dump example >350m

Scale Effect - Normal Stress



What has been used until now?

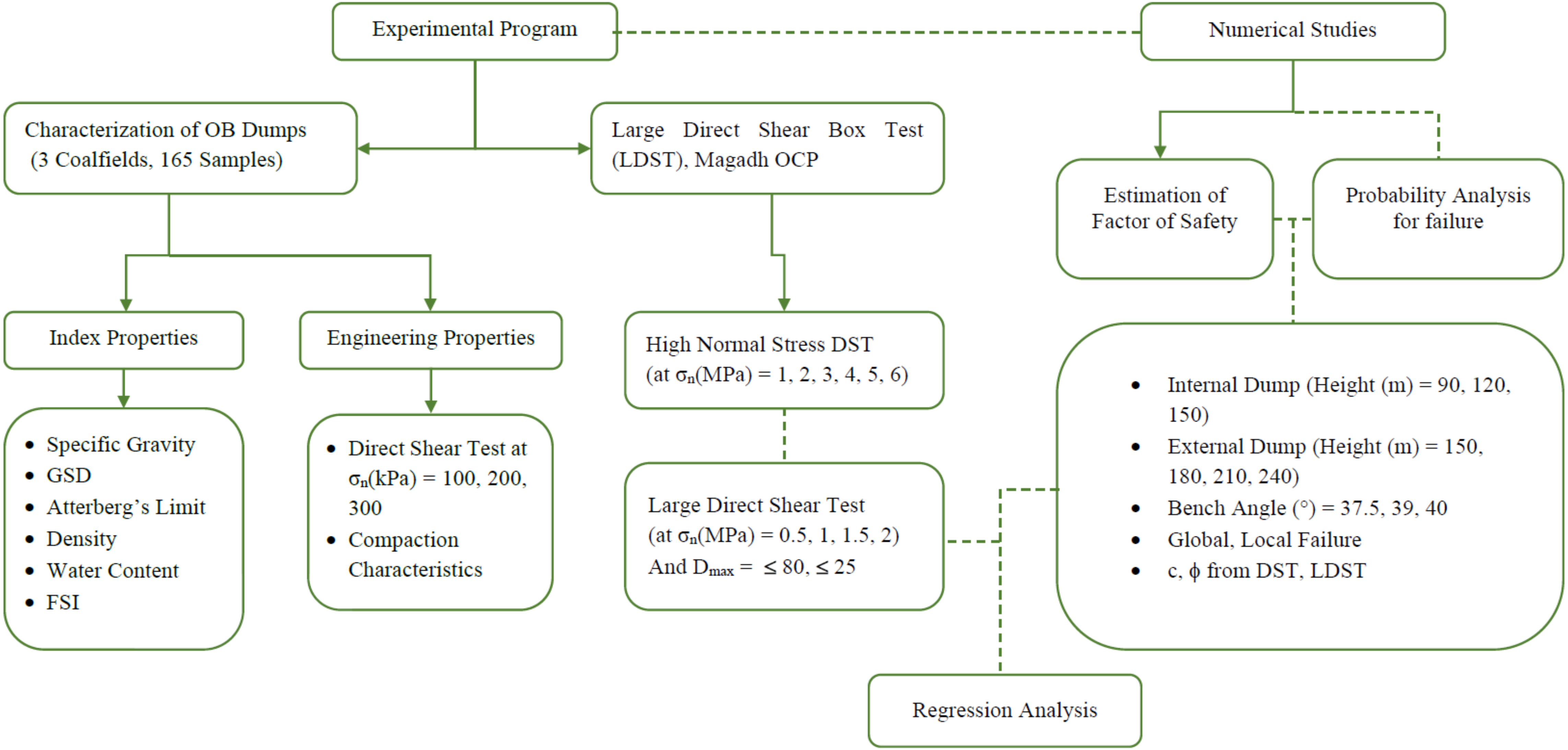
- ✓ OB-specific strength testing is rarely performed
  - Linear Mohr-Coulomb strengths
  - Small-scale tests that simulated stresses for dumps 60-90m high
  - Test data adjusted by back-analysis of failed dumps up to 120m high
  - Verified in practice for dumps **30-120m high**

- ✓ What about high dumps?
  - For rockfill dam design, there is a broad acceptance of curvilinear shear strength envelopes.
  - If this was true for Coal mine OB, extrapolation of linear strength envelopes to cover the stress range for high dumps may over estimate shear strength to an unknown degree.

Need to Focus Our Study On

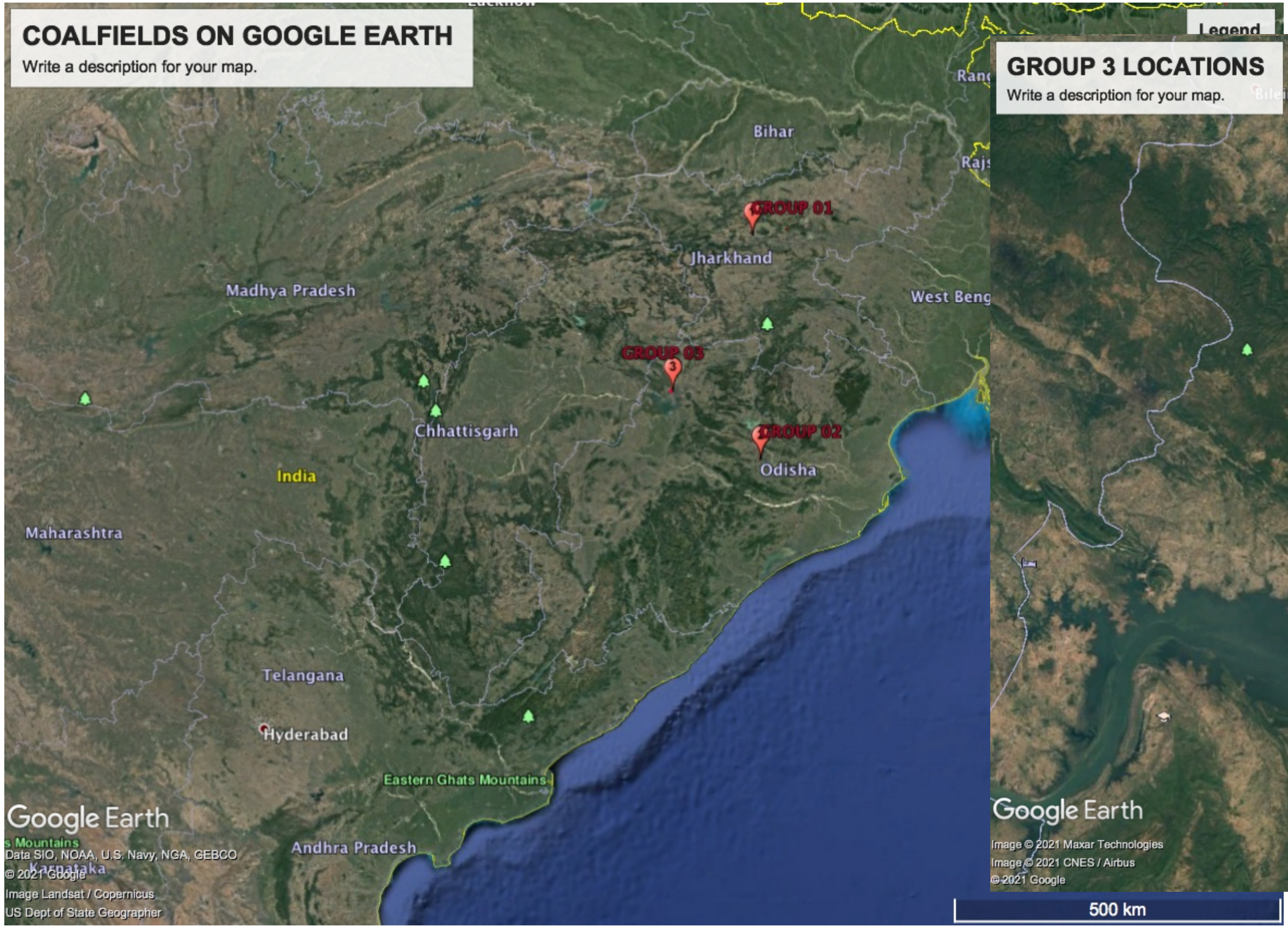
- Geotechnical characterization for overburden dumps (OB) of Opencast Coal Mines in major coalfields in India.
- Design and development of Large-Scale Direct Shear Testing Machine for testing of representative OB dump samples from Opencast Coal mines.
- Testing of representative OB materials in Large Direct Shear Machine for varying stress and gradation.
- Stability Analysis of OB dumps for varying strength and slope dimensional parameters and finding out optimal dump geometries.

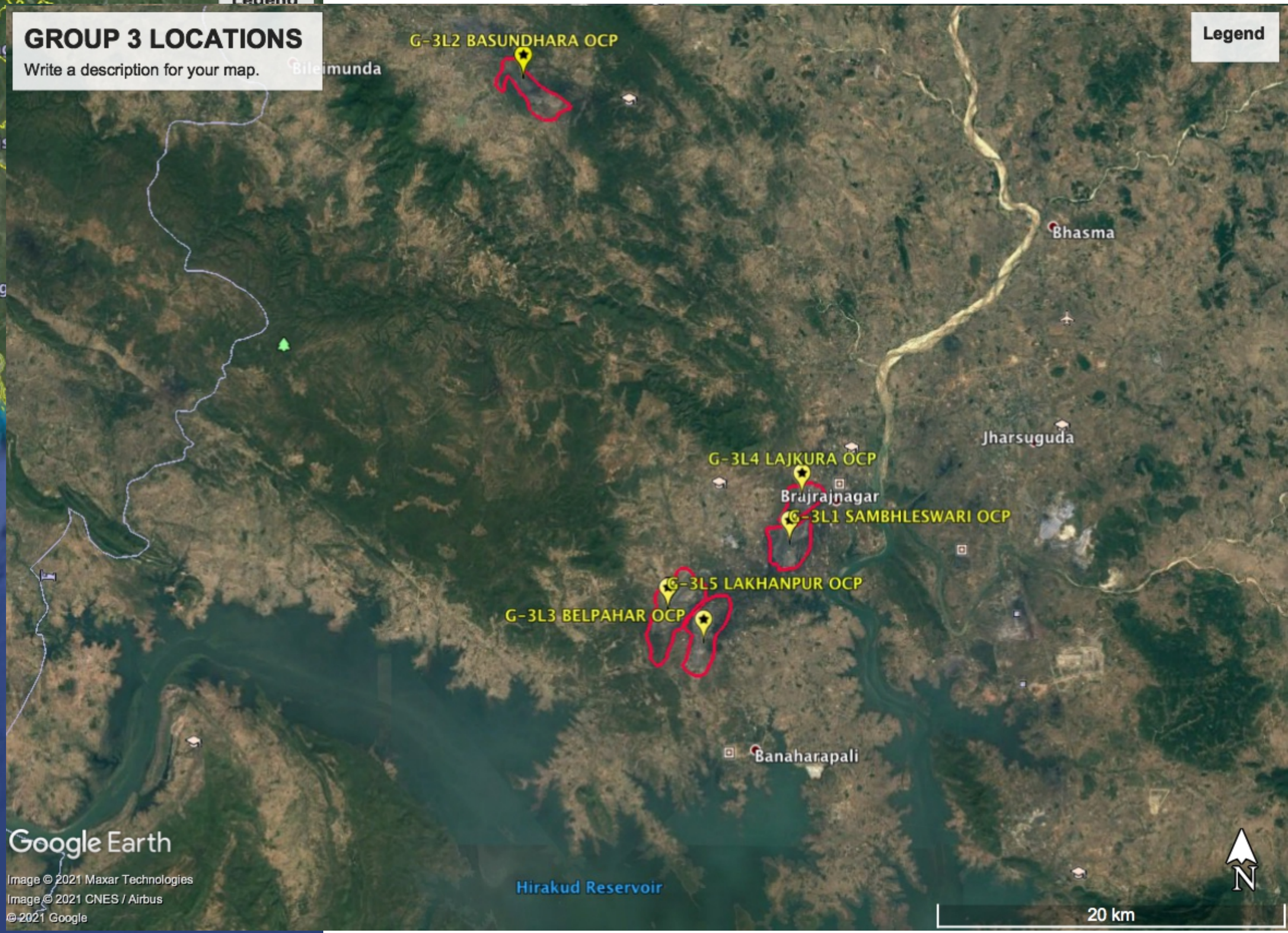
Flow Chart of Research Program



Geotechnical Characterization of Overburden Dumps (OB)

Site Selection





Sample Collection

Sample Collection at Pit1 of G2

Sand Replacement test at Pit1 G2

Details of Selected Project Site

Coal fields	Group-Location	Project	Coal Production (MTPA)	OB Generation (Mm^3/year)	Stripping Ratio
North Karanpura Coalfields	G1-L1	Magadh OCP	20	29.00	1.49
Talcher Coalfields	G2-L1	Ananta OCP	20	44.20	2.21
	G2-L2	Balram OCP	8	11.92	1.49
	G2-L3	Bharatpur OCP	20	16.00	0.80
	G2-L4	Bhuvaneswari OCP	28	19.88	0.71
	G2-L5	Hingula OCP	15	29.25	1.95
	G2-L6	Jagannath OCP	7.5	8.17	1.09
	G2-L7	Kaniha OCP	14	23.00	1.65
	G2-L8	Lingaraj OCP	20	13.80	0.69
IB Valley Coalfields	G3-L1	Sambhelswari OCP	15	27.15	1.81
	G3-L2	Basundhara	8	14.48	1.81
	G3-L3	Belpahar OCP	9	27.36	3.04
	G3-L4	Lajkura OCP	4.5	15.30	3.40
	G3-L5	Lakhanpur OCP	21	50.82	2.42

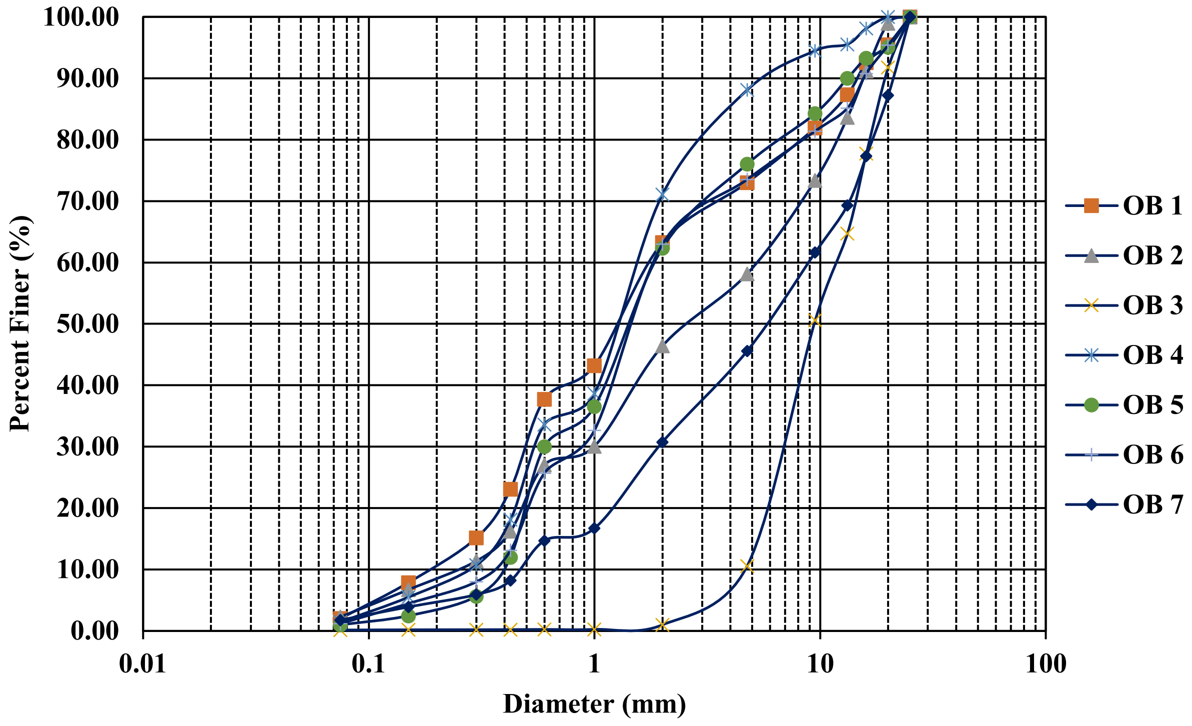
Details of Sampling Pits

Group	Coalfield	Location	Project	Pits/Samples
G1	North Karanpura Coalfields	L1	Magadh OCP	7
G2	Talcher Coalfields	L1	Ananta OCP	9
		L2	Balram OCP	10
		L3	Bharatpur OCP	20
		L4	Bhuvaneswari OCP	12
		L5	Hingula OCP	9
		L6	Jagannath OCP	10
		L7	Kaniha OCP	11
		L8	Lingaraj OCP	11
G3	IB Valley Coalfields	L1	Sambhelswari OCP	10
		L2	Basundhara	14
		L3	Belpahar OCP	14
		L4	Lajkura OCP	20
		L5	Lakhanpur OCP	8
Total No of Samples				**165**

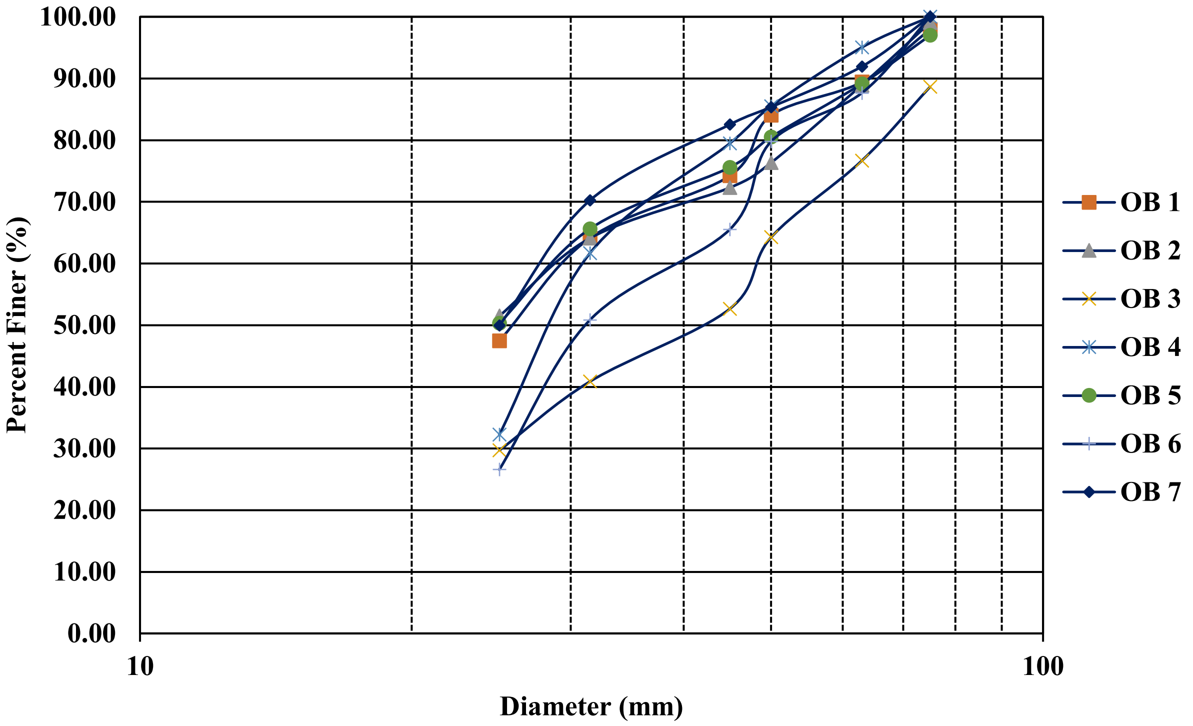
Geotechnical Properties/Parameters of OB Dump at G2-L1

Pit No.	1	2	3	4
Bulk Density (g/cc)	1.58	1.445	1.41	1.59
Dry Densiy (g/cc)	1.52	1.37	1.348	1.47
Field Moisture (%)	4	5	5	8
Gravel (%)	38.1	33.7	20.6	16.5
Sand (%)	50.4	48.5	49.7	59.2
Silt and clay (%)	11.6	17.8	29.7	24.4
Liquid limit (%)	27.4	28.8	30.9	25.7
Plastic Limit (%)	NP	NP	NP	NP
Plasticity Index (%)	NP	NP	NP	NP
FSI (%)	9	0	9	0
Specific Gravity	2.69	2.65	2.65	2.7
OMC (%)	11	12	12	11
MDD (g/cc)	1.90	1.83	1.85	1.90
Cohesion (kPa)	6.67	6.86	5.88	6.77
Angle of Internal Friction (°)	32.0	28.6	29.4	29.5
Permeability (m/s)	4.25×10^{-4}	3.41×10^{-3}	8.44×10^{-3}	5.11×10^{-3}
IS Classification	SM	SM	SM	SM
Compaction Achieved (%)	80.0	75.2	72.5	77.7

Particle Size Distribution from G1-L1

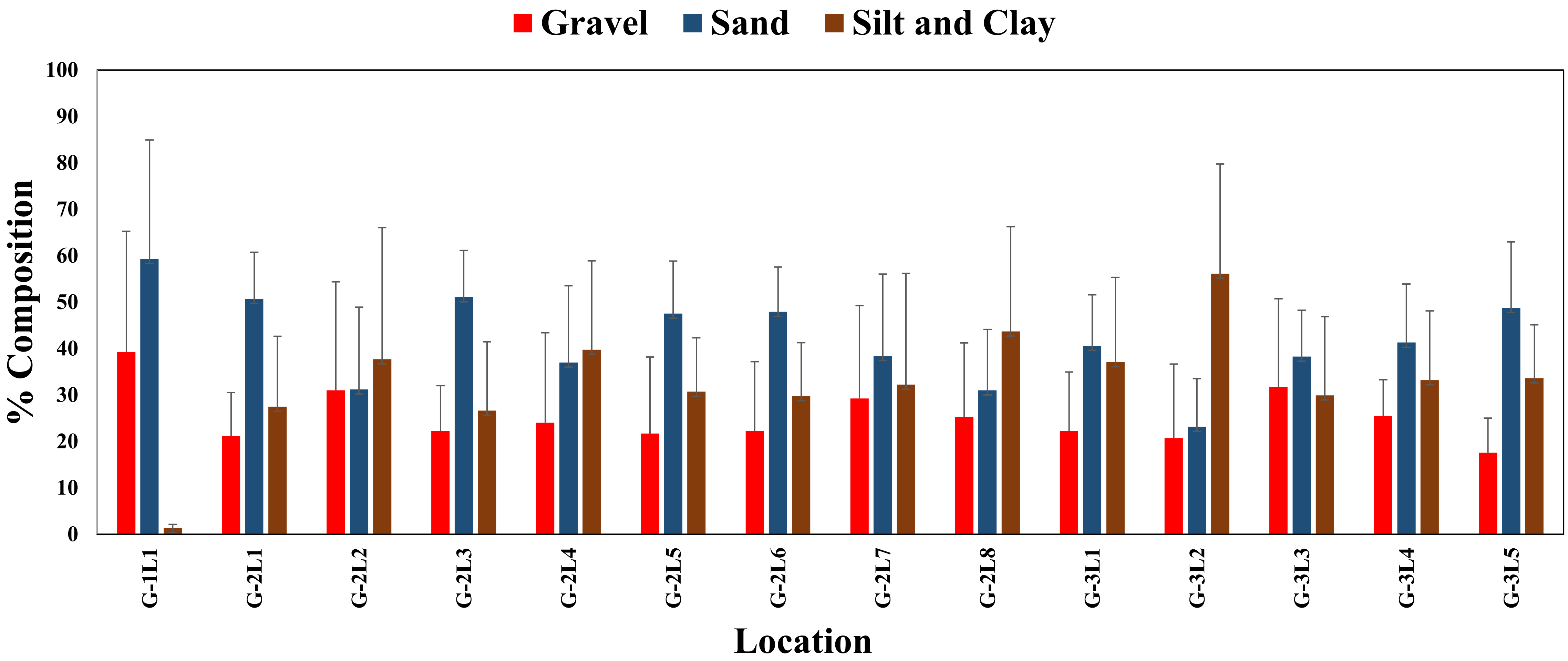


Particle Size Distribution of OB Material from G1-L1 having $D_{max} \leq 25mm$

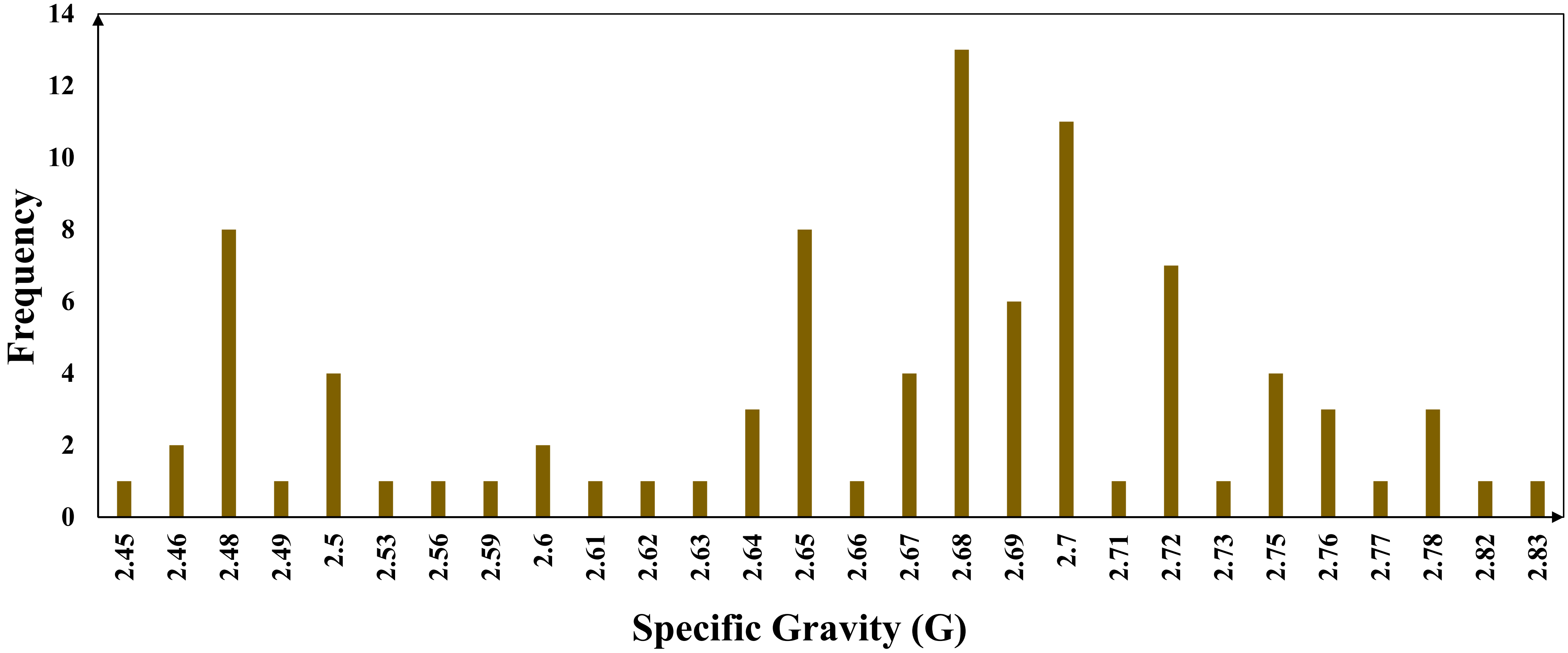


Particle Size Distribution of OB Material from G1-L1 having $D_{max} \leq 80mm$

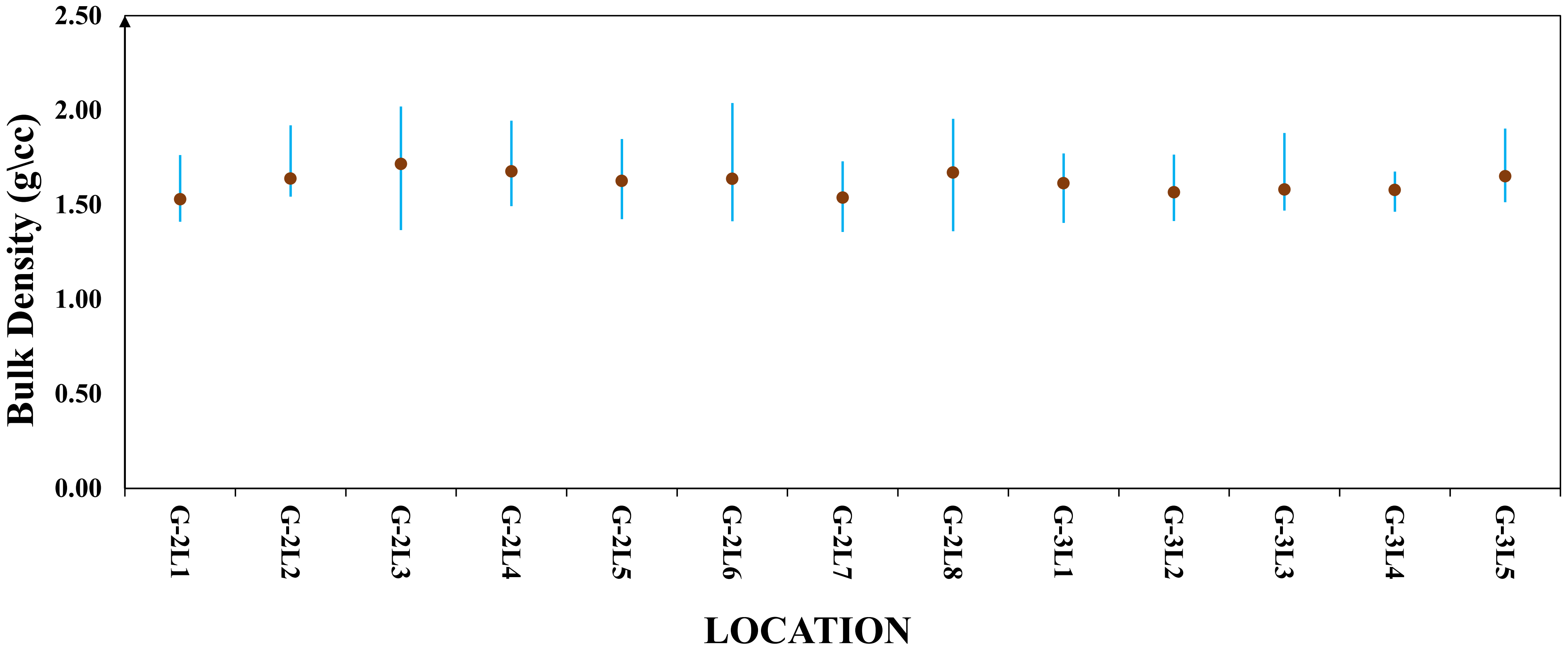
Particle Size Distribution



Specific Gravity (G)



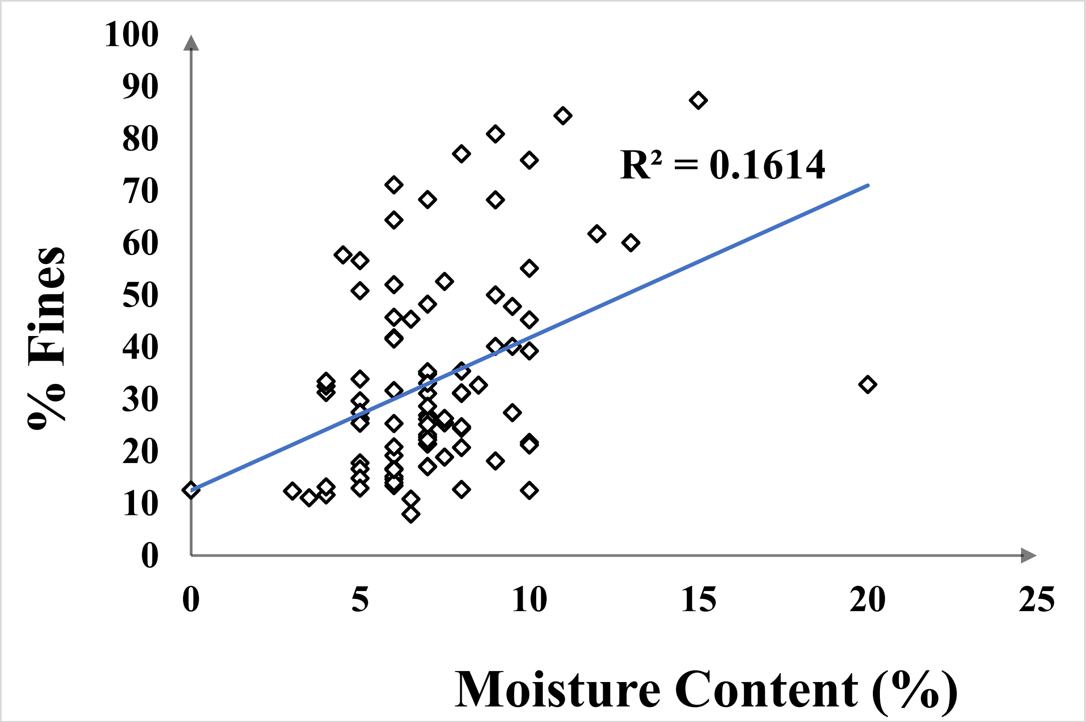
In-Situ Density

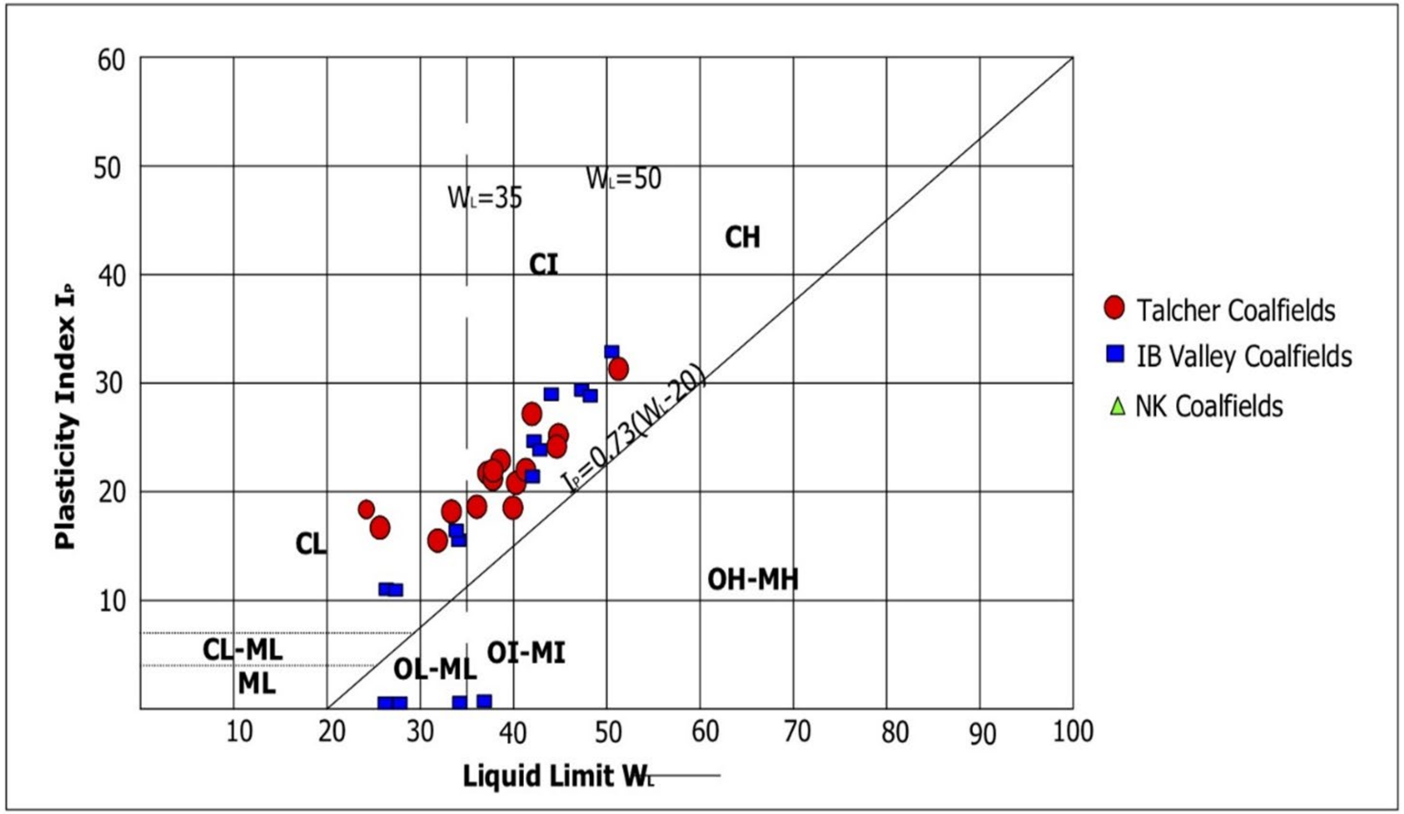


One-way Anova Test for Bulk Density and Specific Gravity

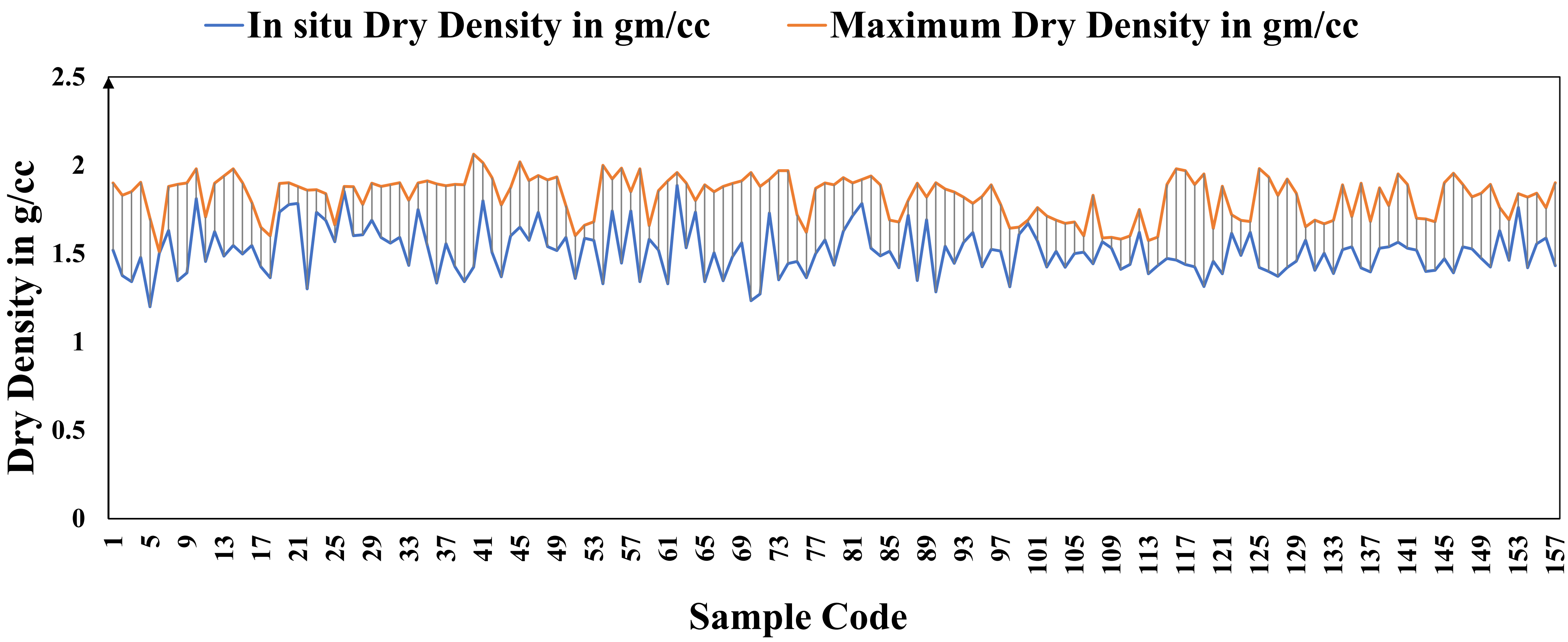
In-situ Bulk Density (g/cc)					
	Sum of Squares	df	Mean Square	F	Sig. (P value)
Between Locations	0.368	7	0.053	2.141	0.048
Within Locations	2.039	83	0.025		
Total	2.407	90			
Specific Gravity (G)					
	Sum of Squares	df	Mean Square	F	Sig. (P value)
Between Locations	0.062	7	0.009	1.008	0.432
Within Locations	0.727	83	0.009		
Total	0.788	90			

Plasticity Chart of Soils from Various Coal Fields

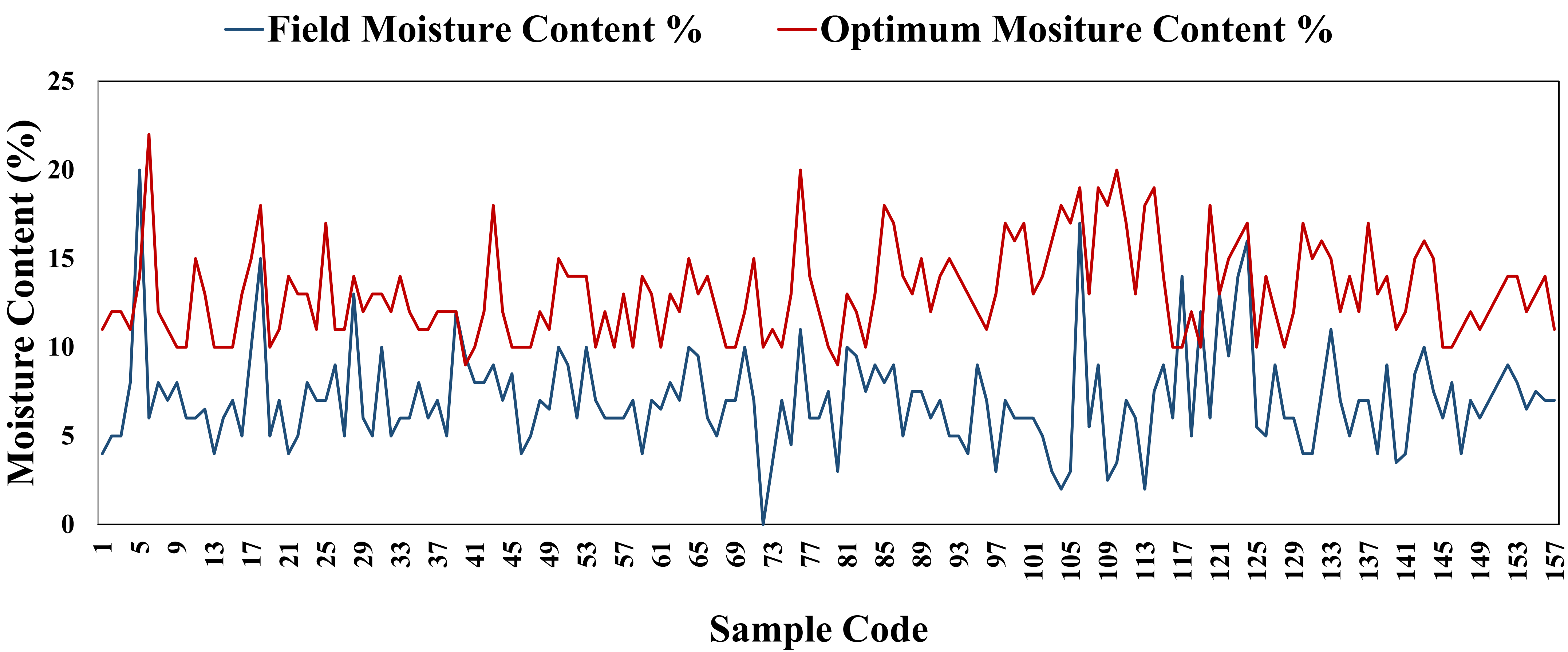




Comparison Chart of Max. Dry Density and In-situ Dry Density



Comparison Chart of Field Moisture Content and OMC



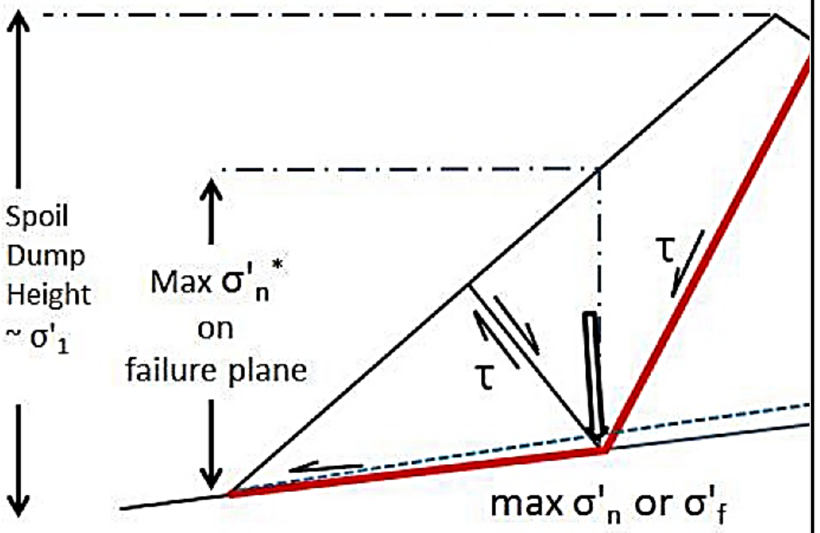
Shear Strength Parameters of OB Dump Material for All Locations

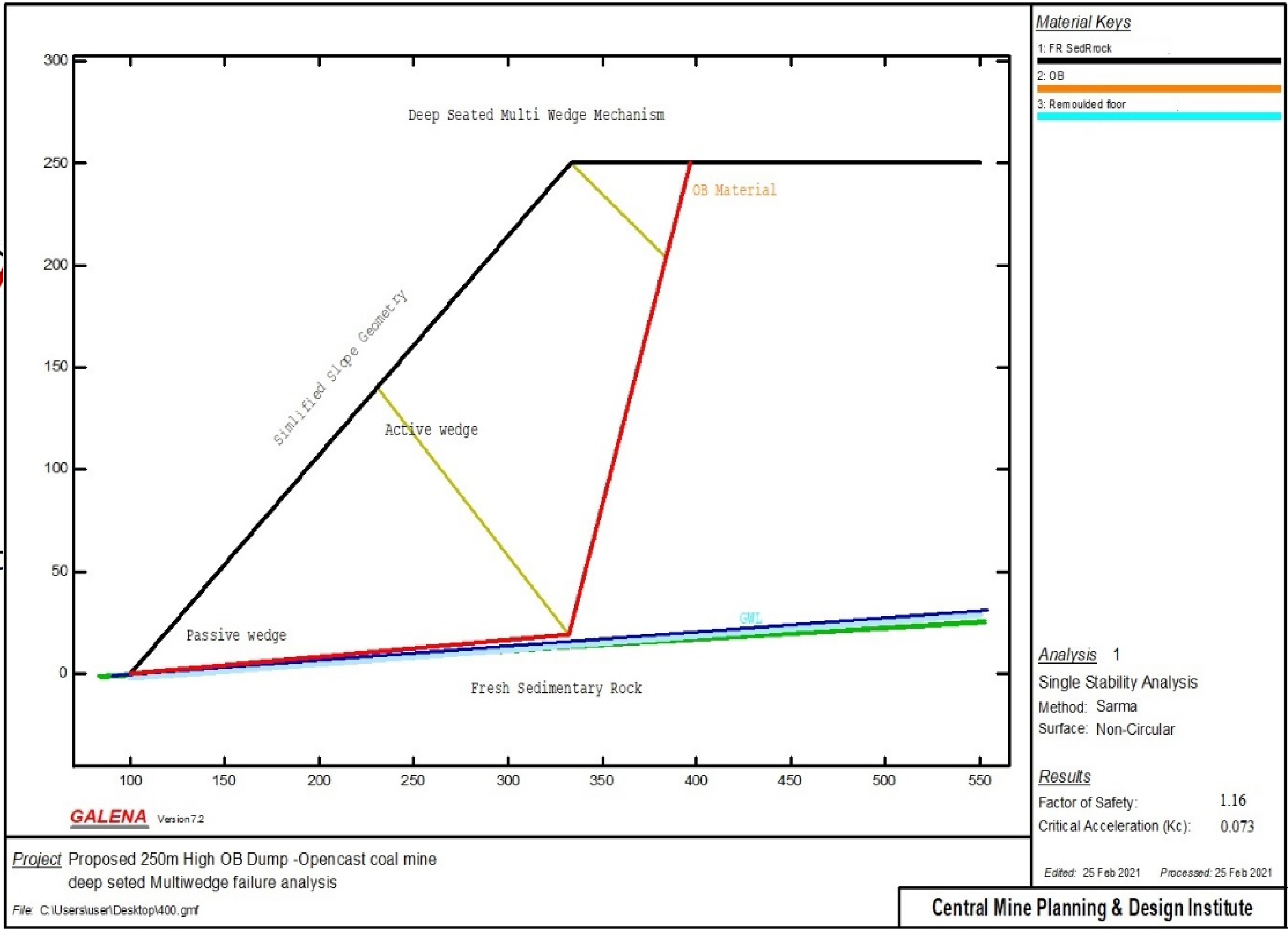
Location	c (kPa)				ϕ (°)			
	Min	Max	Mean	SD	Min	Max	Mean	SD
G1-L1	23.04	88.25	62.48	22.07	42.92	47.98	45.50	2.07
G2-L1	1.96	58.84	13.99	18.52	10.90	32.00	26.59	6.29
G2-L2	4.90	43.64	20.60	15.94	11.00	34.30	24.88	9.40
G2-L3	3.63	40.99	9.11	10.35	12.00	35.00	30.10	6.37
G2-L4	4.81	48.35	17.89	17.31	13.00	37.00	27.82	8.07
G2-L5	3.92	23.54	10.87	7.75	23.00	35.00	29.59	3.52
G2-L6	5.88	46.09	15.98	11.97	15.00	33.00	26.20	5.59
G2-L7	3.92	47.07	17.47	14.77	12.00	36.00	25.14	8.25
G2-L8	4.71	48.64	27.07	18.90	11.00	35.00	22.53	9.09
G3-L1	2.94	8.63	6.14	1.83	27.00	33.00	30.62	1.67
G3-L2	4.90	42.16	24.79	15.05	10.00	35.30	19.89	10.14
G3-L3	2.94	32.36	7.67	7.25	20.00	36.10	31.15	3.85
G3-L4	5.79	22.75	9.86	4.36	20.00	34.00	28.90	3.77
G3-L5	4.02	8.04	6.06	1.35	31.10	34.00	32.30	0.86

Design and Development of Large Direct Shear Machine

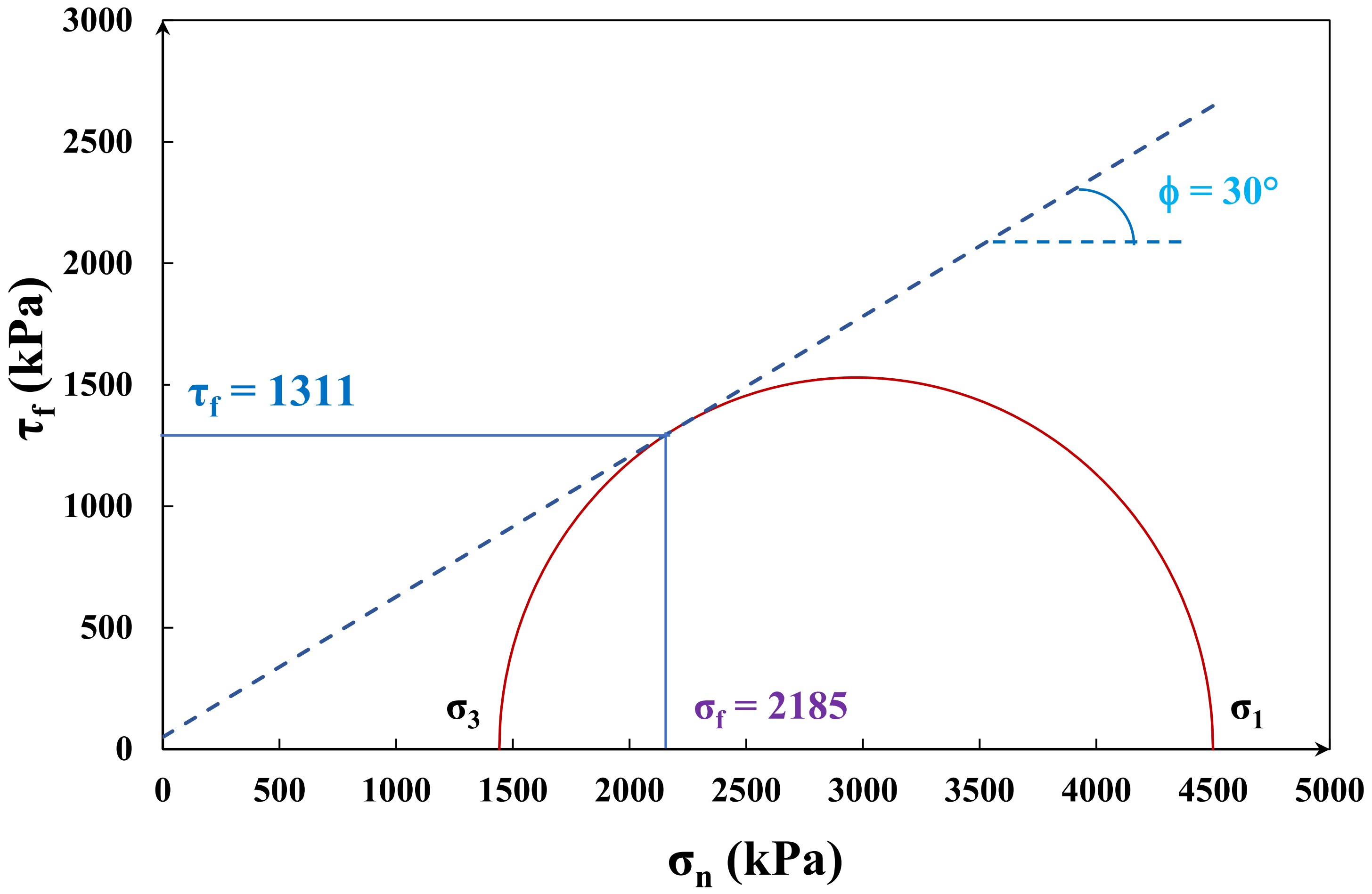
Estimation of Stress States for Very High Dumps

Limit Equilibrium Analysis





Mohr Circle Analysis



Input Parameters

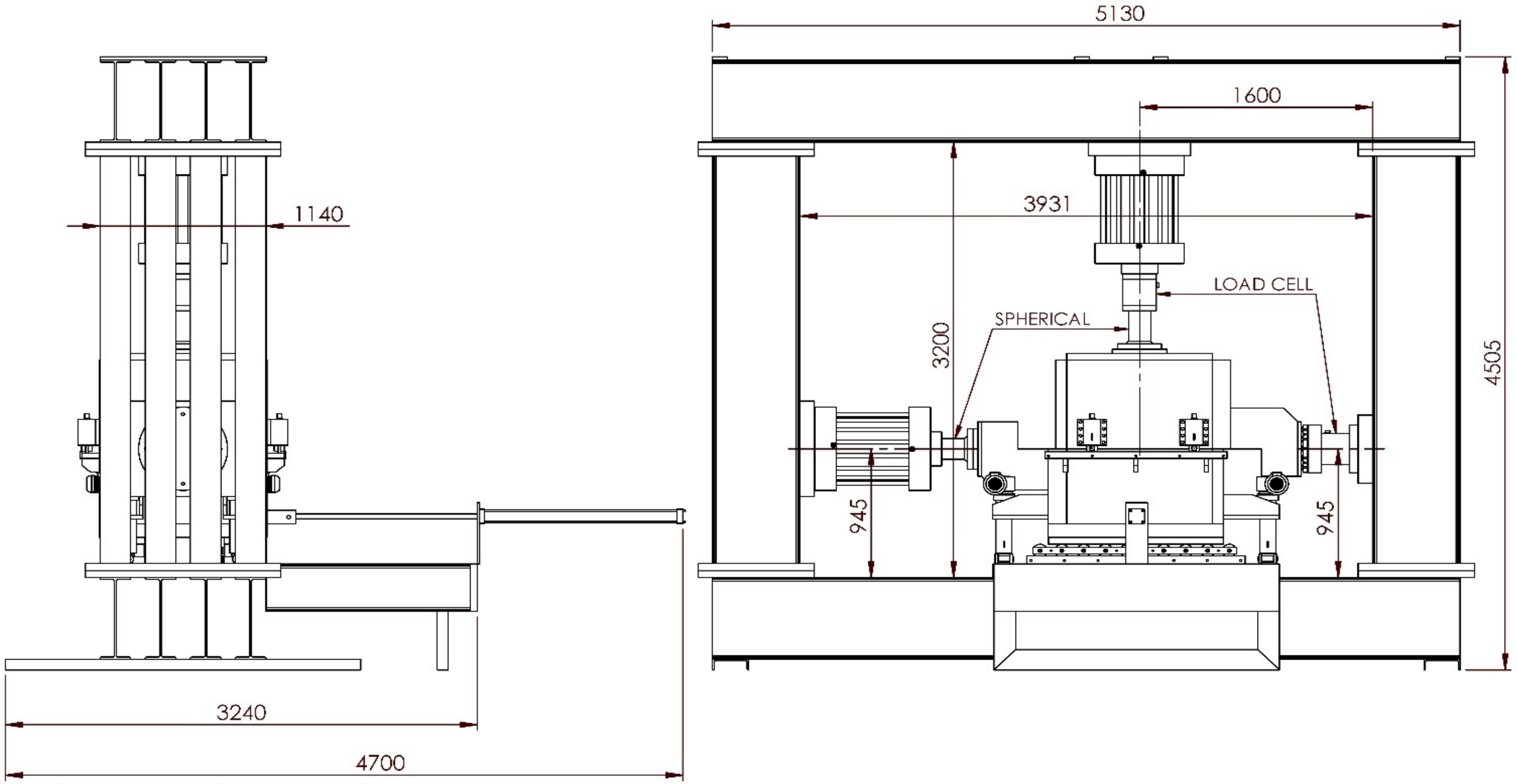
c = 50 kPa

$\phi = 30°$

$\gamma = 18\ kN/m^3$

Height of Over Burden 250m

Assembly of Large Direct Shear Machine with all Components



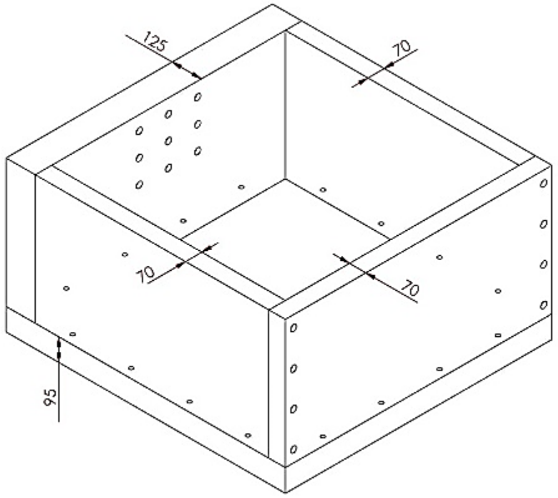
Split Shear Box

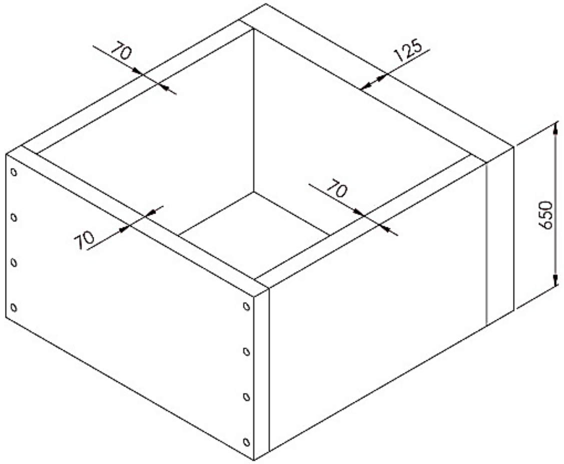
As per ASTM D3080-98

✓The minimum specimen width for square specimens, shall be 2.0 in. [50 mm], or not less than ten (10) times the maximum particle size diameter, whichever is larger.

✓The minimum initial specimen thickness shall be 0.5 in. [13 mm], but not less than six (6) times the maximum particle diameter.

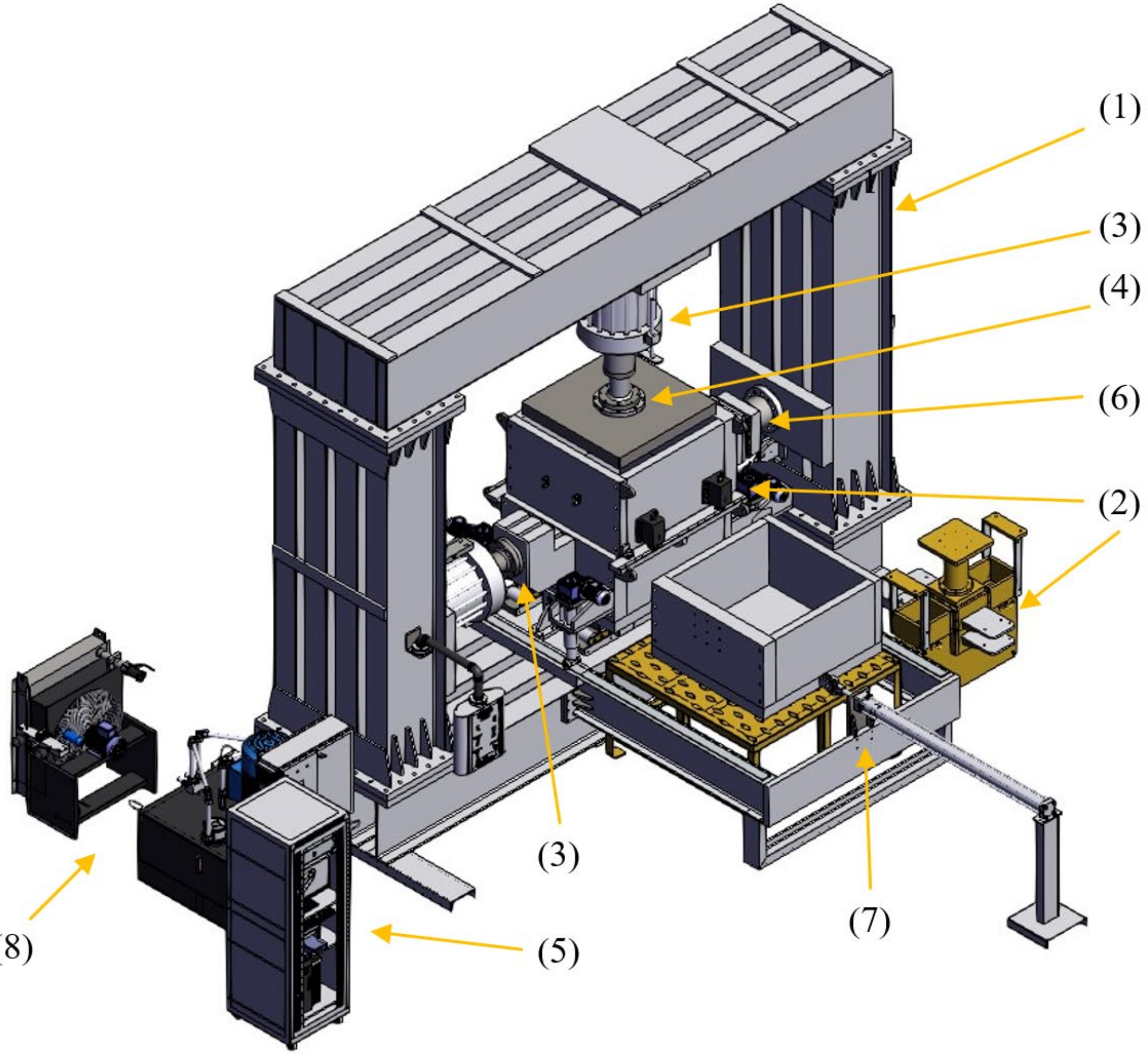
✓The minimum specimen width to thickness ratio shall be 2:1.



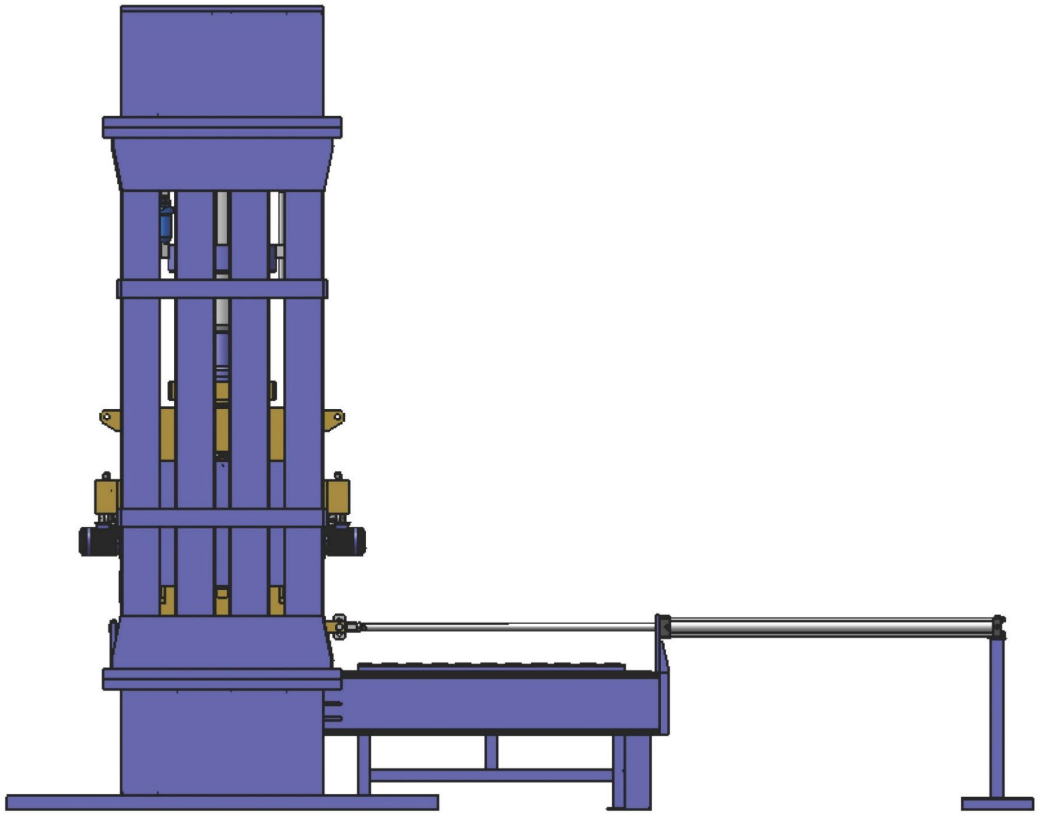


LDSM Assembly

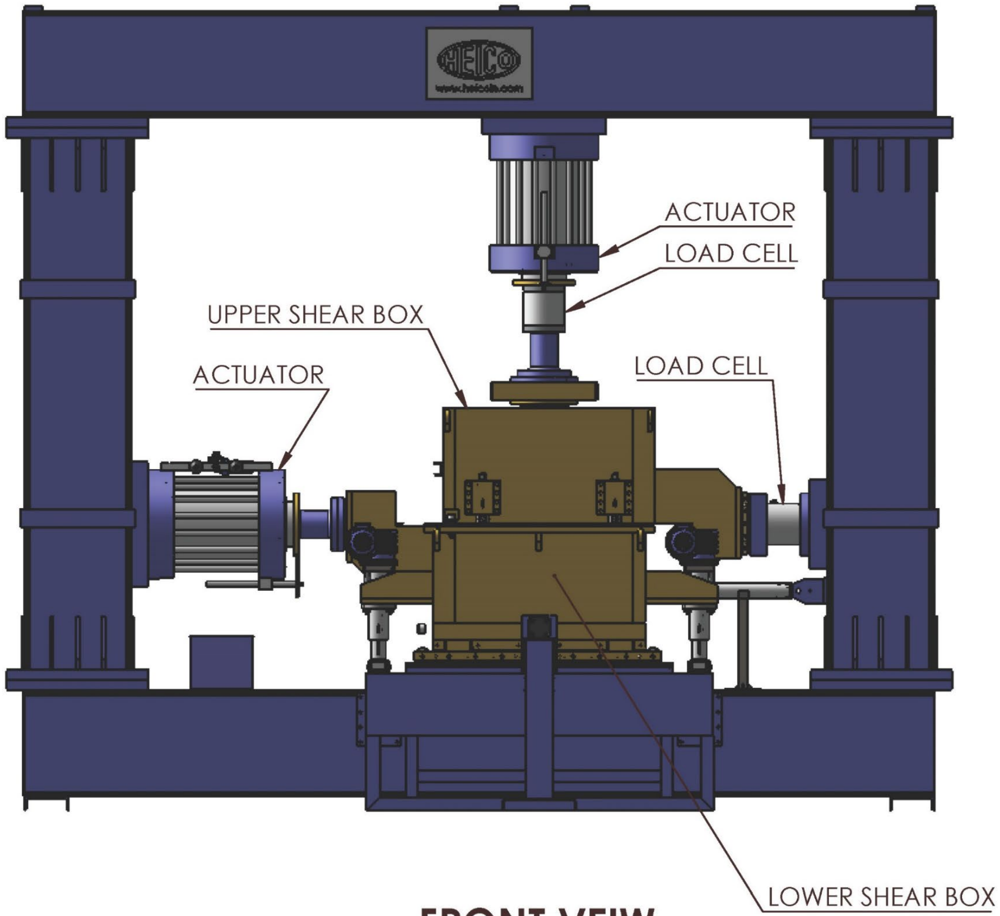
(1) Loading System
(2) Shear Box Assembly
(3) Servo Hydraulic Actuators
(4) Top Loading Pad with Spherical Seating
(5) PC based DAQ Control Unit
(6) Load Cell
(7) Push and Pull Arrangement
(8) Hydraulic Power Pack with Air Cooler



Assembly of Large Direct Shear Machine with all Components



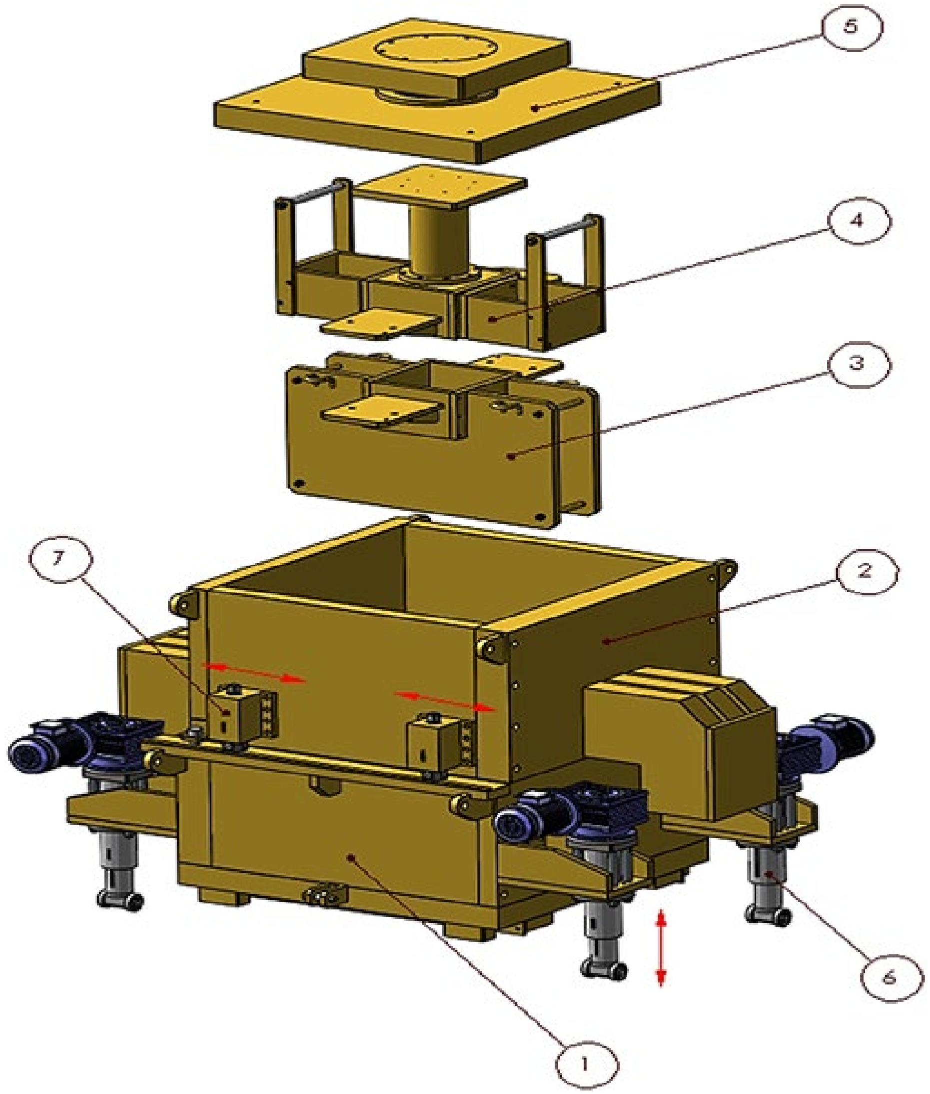
SIDE VEIW



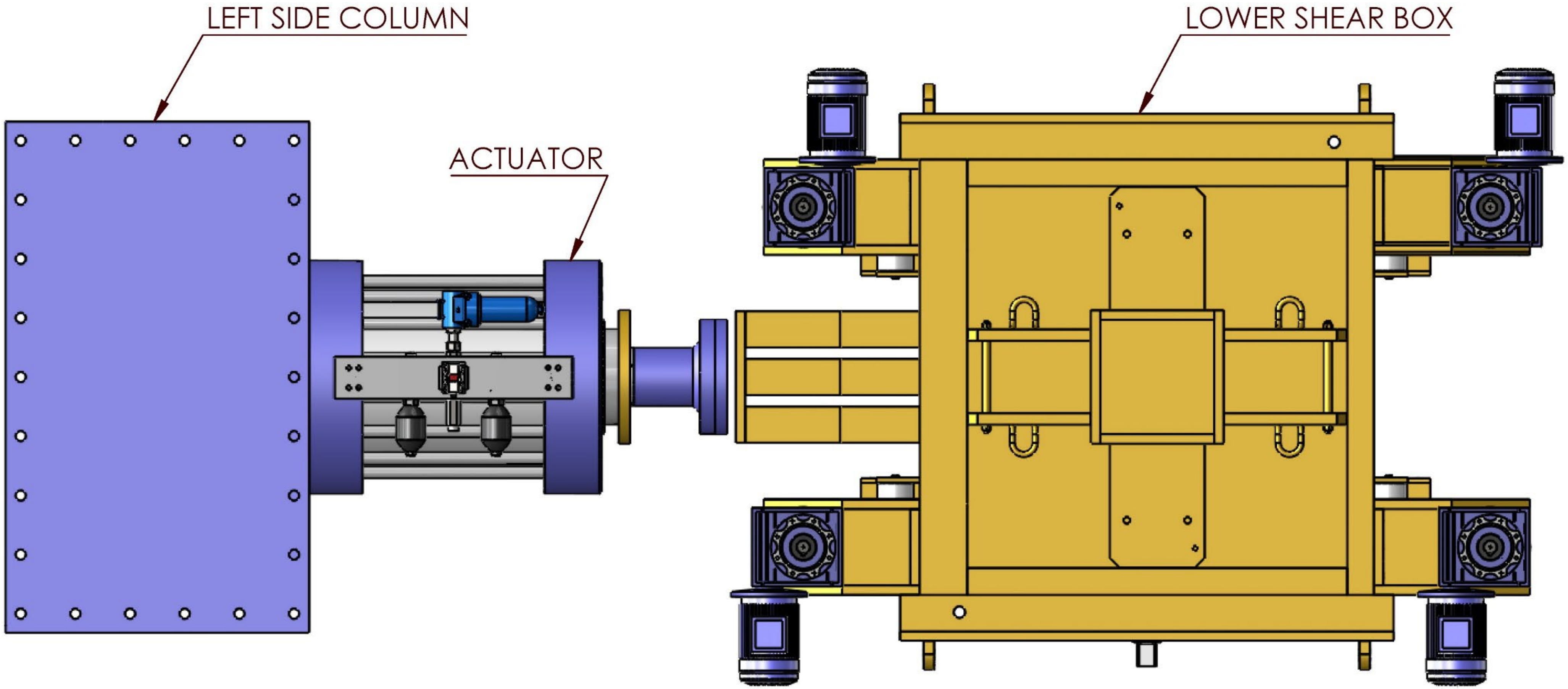
FRONT VEIW

Split Shear Box's Components

1. Bottom Box (1000mm×1000mm)
2. Upper Box (1000mm×1000mm)
3. Bottom Box (300mm×300mm)
4. Upper Box (300mm×300mm)
5. Spherical Seating
6. Assembly lifting-Jack
7. Upper-Box lifting Jack



Top View of Lower Shear Box With Actuator Alignment

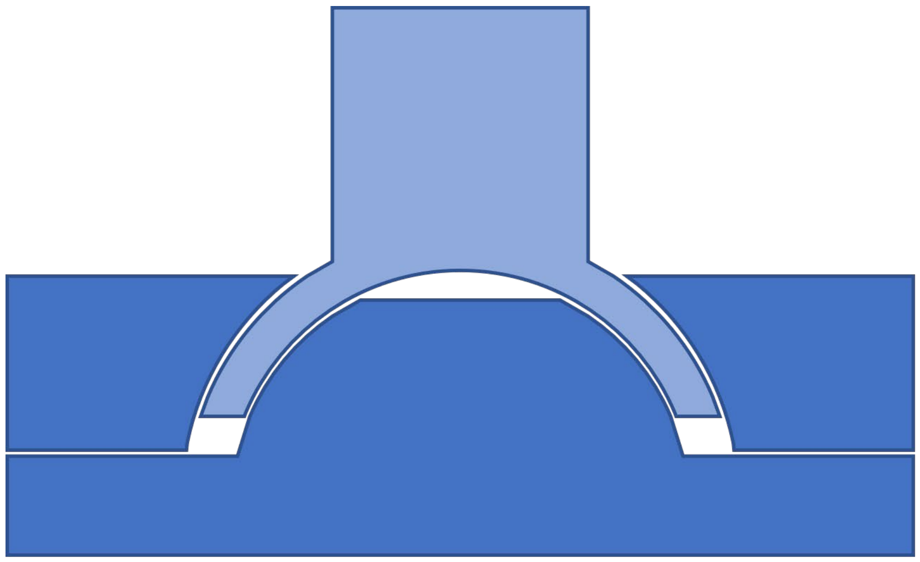


Establishment of Equipment Facility

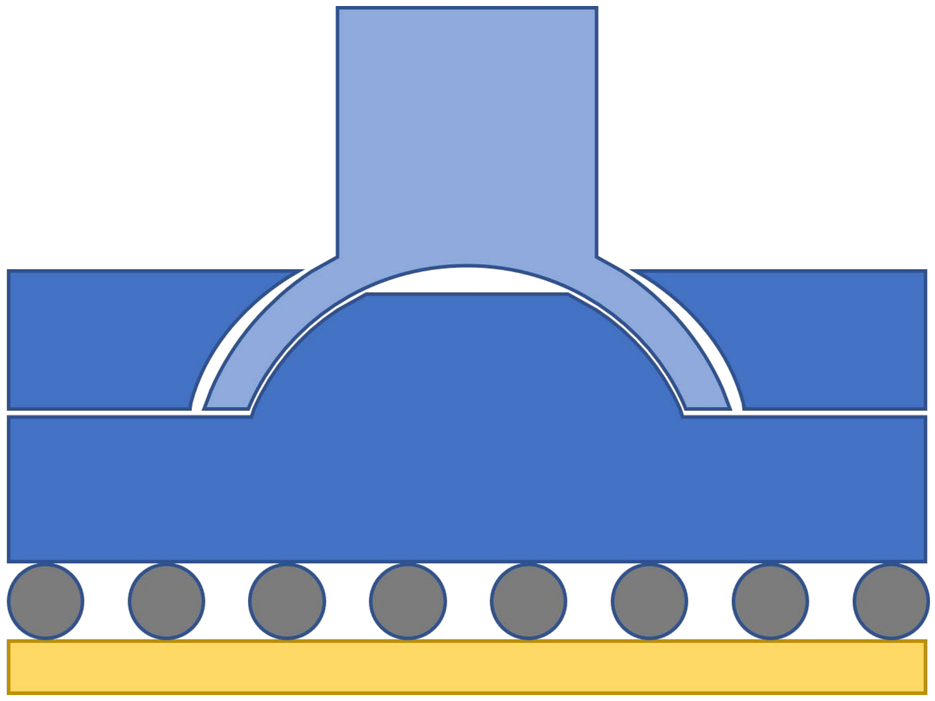
Technical Specification of LDSM

Sr. No.	Technical Detail	Specification
1	Maximum Normal Load	2500kN
2	Maximum Shearing Load	2500KN
3	Normal Load Range	10-2500kN
4	Shear Strain Rate	0.001mm/sec - 1mm/sec
5	Specimen Size	1000mm×1000mm×1000mm, 300mm×300xmm×300mm
6	Normal Load Cell Capacity	2500kN
7	Shear Load Cell Capacity	2500kN
8	Safe Over Load	150% of Rated Capacity
9	Ultimate Over load	300% of Rated Capacity
10	Displacement Speed	$\leq$ 10 m/s.

Top Loading Pad with Spherical Seating



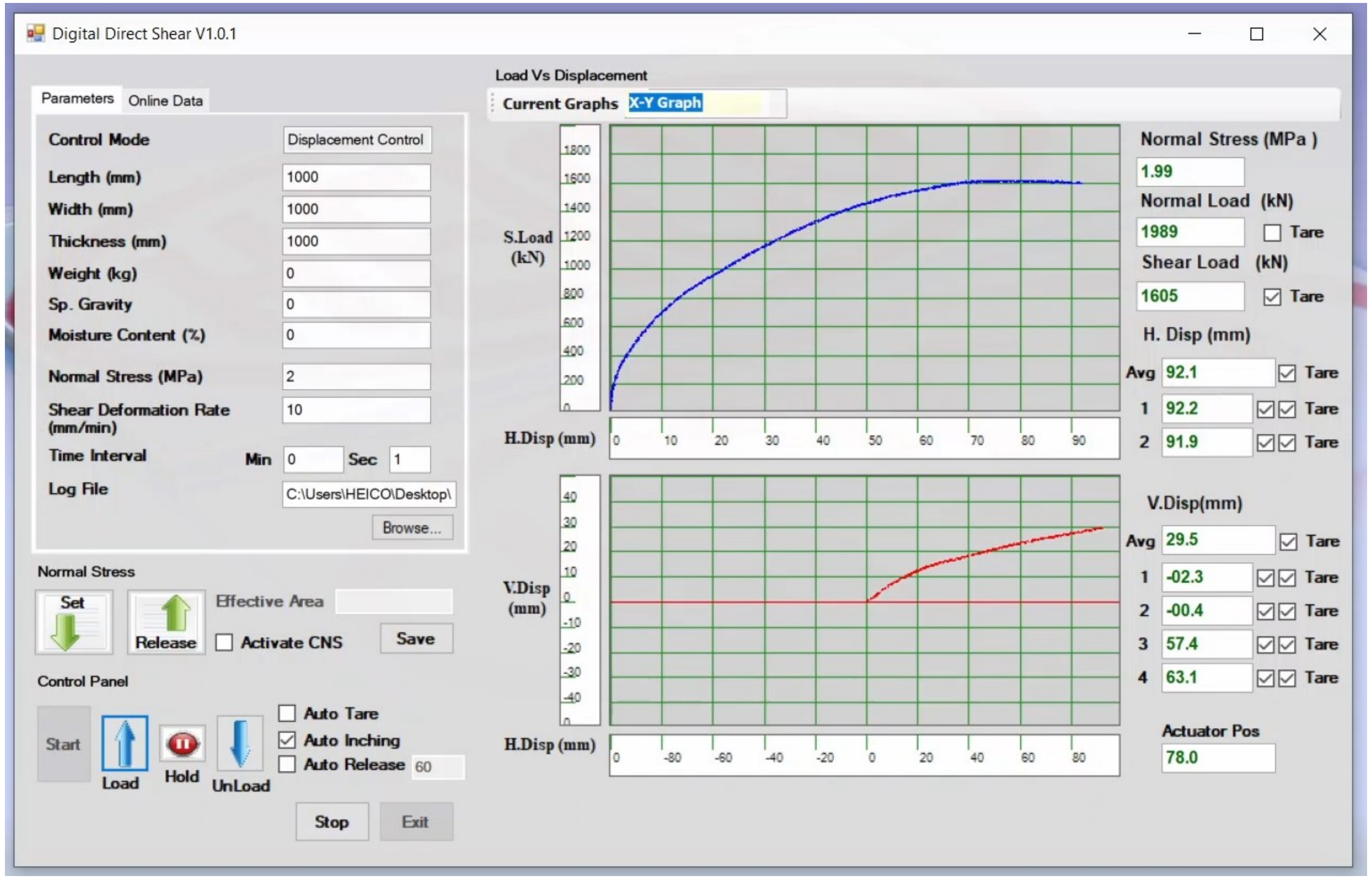
Spherical seating for equal stress



Spherical seating for equal strains

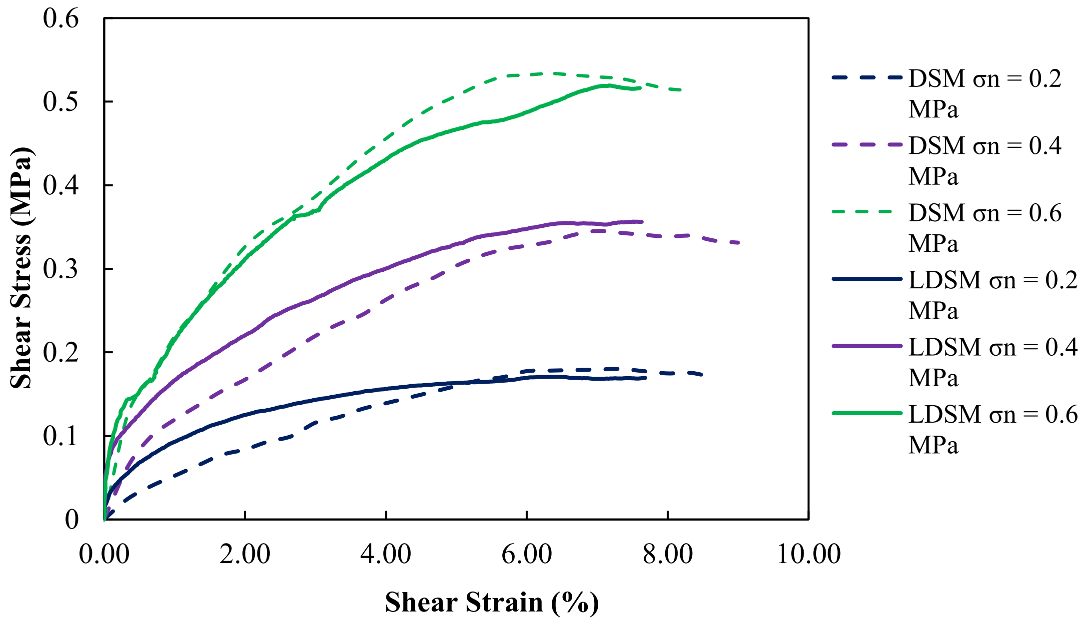
PC-Based Data Acquisition, Control and Display System

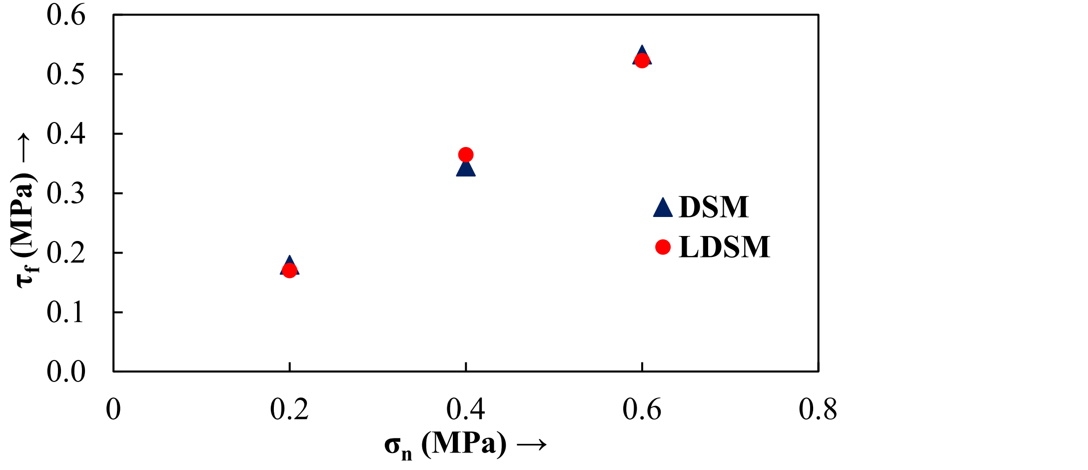
- An automated/manually controlled sequence for initial lowering of the cylinders to make first contact with the top plate.
- Based on the control logic in conjunction with servo valve feedback system.
- Control of the variables through system only.
- Real-time data chart and data logging.
- Facility to toggle between CNS and CNL condition.



Calibration and Model Tests

- The load cells were calibrated using NPL certified proving rings of 3000kN capacity in accordance to IS 1828 Part I.
- LVDTs were calibrated for deformation upto 100mm (vertical) and 200mm (horizontal) with 0.01mm preciseness for error in deformation within permissible limits.
- Calibration for shearing was based on a comparison of LDSM and traditional direct shear tests of 300mm×300mm (DSM) using a well-tested and consistently graded dry sand.





Testing of Representative OB Materials in Large Direct Shear Machine

Variables Involved in Testing

Considering all the above aspects, following variations were performed for DST, LDST:

- 7 OB dump materials : OB1, OB2, OB3, OB4, OB5, OB6 and OB7
- $D_{max:}$: ≤25mm, and ≤80mm
- Box size : 300mm×300mm, 1000mm×1000mm
- Low Normal Stress : 100, 200, 300, 500, 1000, 1500, 2000 kPa
- High Normal Stress: 1000, 2000, 3000, 4000, 5000, 6000 kPa

A total of 119 tests performed considering all the stated variations above and by maintaining equal compaction effort, moisture content.

Bulk Samples Collection

Collection and Packing of Samples from OB dump

Photograph of OB-5 ,7 Showing Composition of Various Particle Size

The Index and Engineering Properties of Magadh OCP (G1-L1)

Soil	OB-1	OB-2	OB-3	OB-4	OB-5	OB-6	OB-7
Field Moisture (%)	7.2	7.9	3.2	4.8	5.5	6.5	5.2
Gravel (%)	26.99	41.84	89.42	11.90	23.96	26.47	54.39
Sand (%)	71.02	55.88	10.46	86.66	75.08	72.35	43.85
Silt and clay (%)	1.99	2.28	0.12	1.45	0.96	1.17	1.76
D_{60} (mm)	1.8	5.2	12	1.6	1.8	1.8	9
D_{30} (mm)	0.5	1	7	0.55	0.6	0.9	2
D_{10} (mm)	0.19	0.25	4.80	0.30	0.40	0.36	0.48
C_u (mm)	9.47	20.80	2.50	5.33	4.50	5.00	18.75
C_c (mm)	0.73	0.77	0.85	0.63	0.50	1.25	0.93
FSI (%)	0	0	0	0	0	0	0
Specific Gravity	2.44	2.50	2.12	2.62	2.62	2.60	2.57
OMC (%)	14	12	-	10	13	12	13
MDD (g/cc)	1.71	1.82	-	2	1.93	1.94	1.82
Cohesion (kPa)	6.62	8.00	2.24	8.34	8.26	5.76	5.16
Angle of Internal Friction (°)	36.32	36.87	35.75	32.82	33.22	37.95	36.13
IS Classification	SW	SW	GP	SP	SP	SP	SW

Compaction Efforts (IS 2720 Part VII)

- Compaction energy in IS light compaction test,

$$= \frac{2.6\ (\mathrm{kgf}) \times 0.31 (\mathrm{m}) \times 3 (\mathrm{layers}) \times 25 (\mathrm{blows/layer})}{10^3 \times 10^{-6} (\mathrm{m}^3)} = \boldsymbol{60450\ kgf\ m/m^3}$$

For LDSM, Compaction energy per drop provided by the rammer per cu.m. of the soil, for 15cm dia drop hammer,

$$= \frac{5\ (kgf) \times 0.40 (m)}{(0.5/3)(layer\ thickness)(\pi \times 0.15^2 (diameter)/4}$$

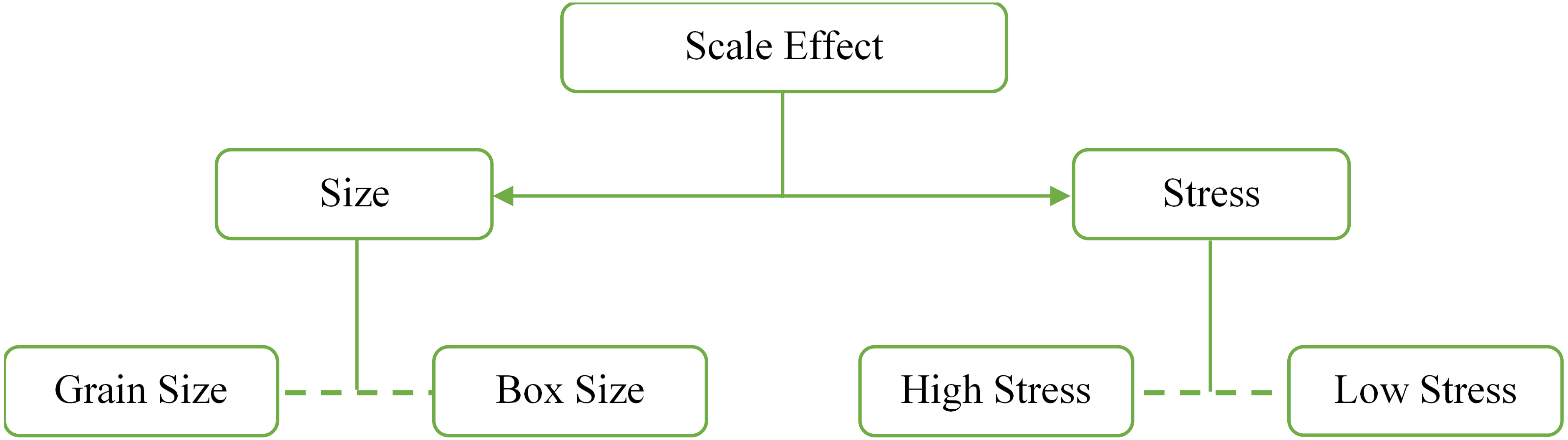
$$= 679.4\ kgf\ m/m^3$$

Considering 50% overlap in each pass over a layer, no. of blows required for each layer,

$$= \frac{60450\ kgf\ m/m^3}{1.5 \times 679.4\ kgf\ m/m^3} = 59.31 \approx \boldsymbol{60\ blows}$$

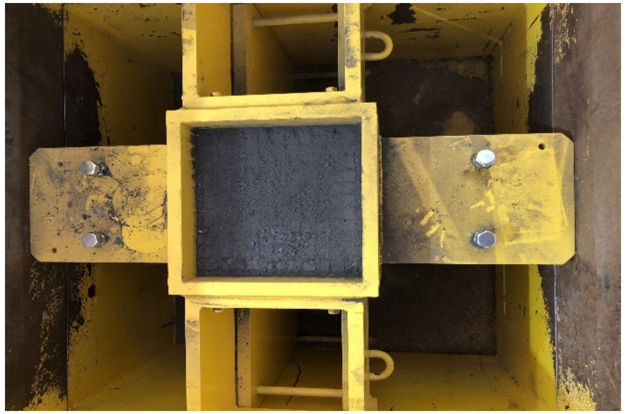
Similarly, for DSM no. blows required for each layer worked out to be **8 per layer**.

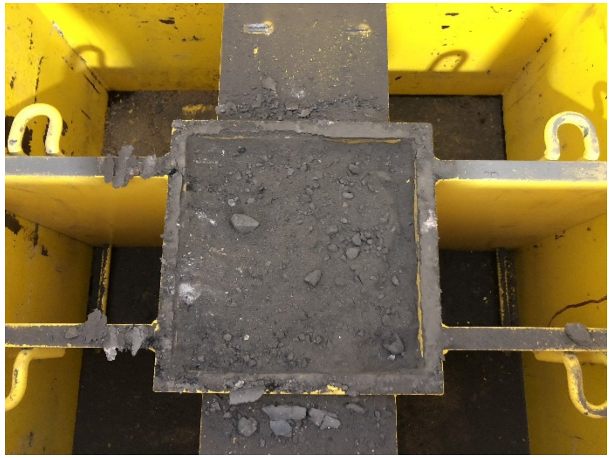
Scale Effect Considerations

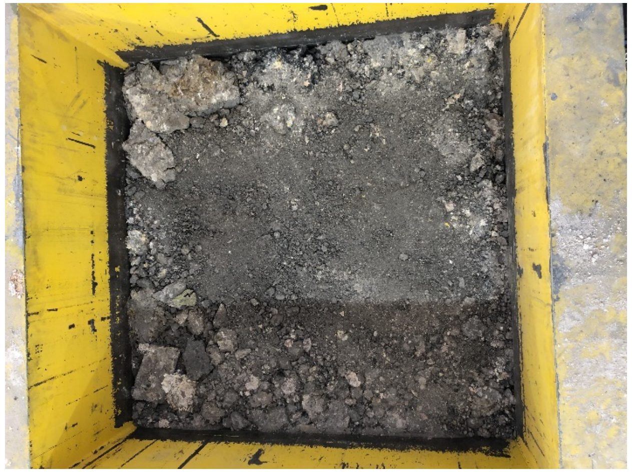


- ✓ Degree to which the grading of a OB dump sample must be downscaled to comply with device capacity, such that the influence of prototype-sized particles on shear strength is not anomalous.
- ✓ Normal stress limits of the test apparatus; and if the failure envelope developed from measured strengths can be reliably extrapolated out to the much-higher stress ranges to simulate field-conditions for dumps of current and future heights.

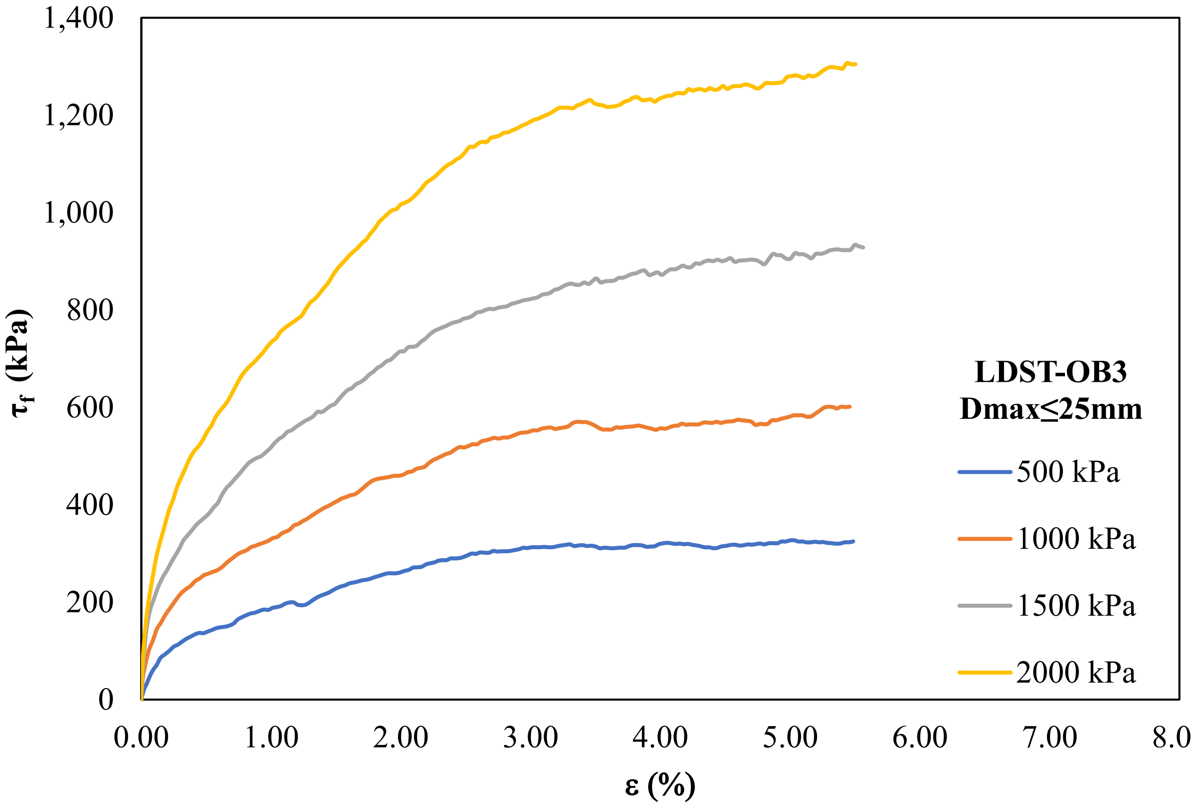
Sample Specimens while Testing

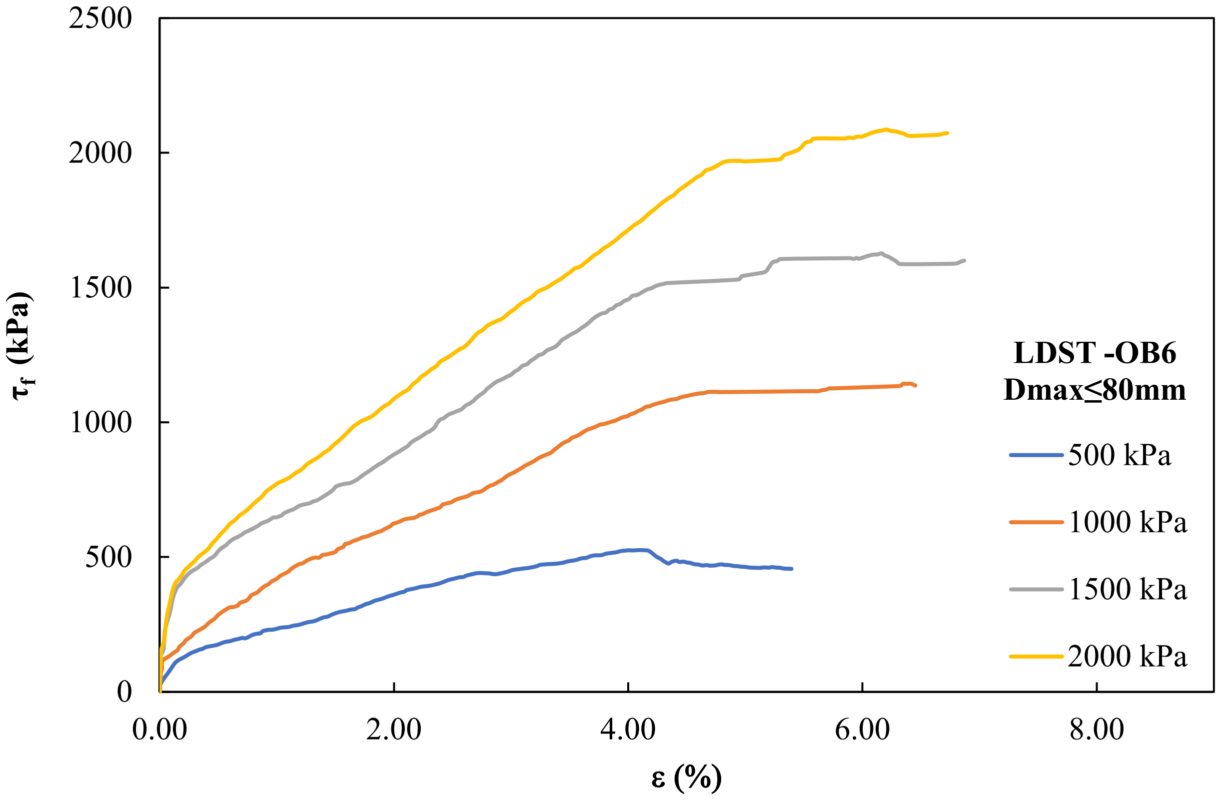




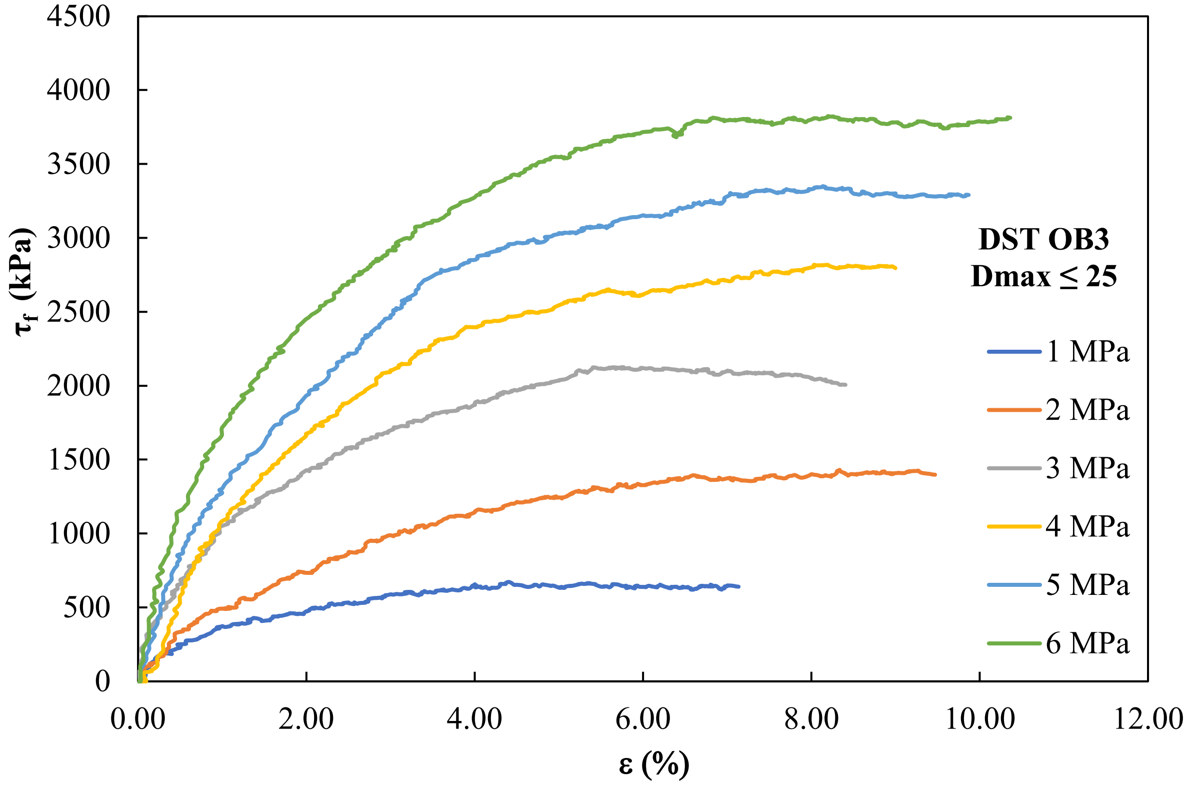


Typical Shear Stress vs Shear Strain Plots



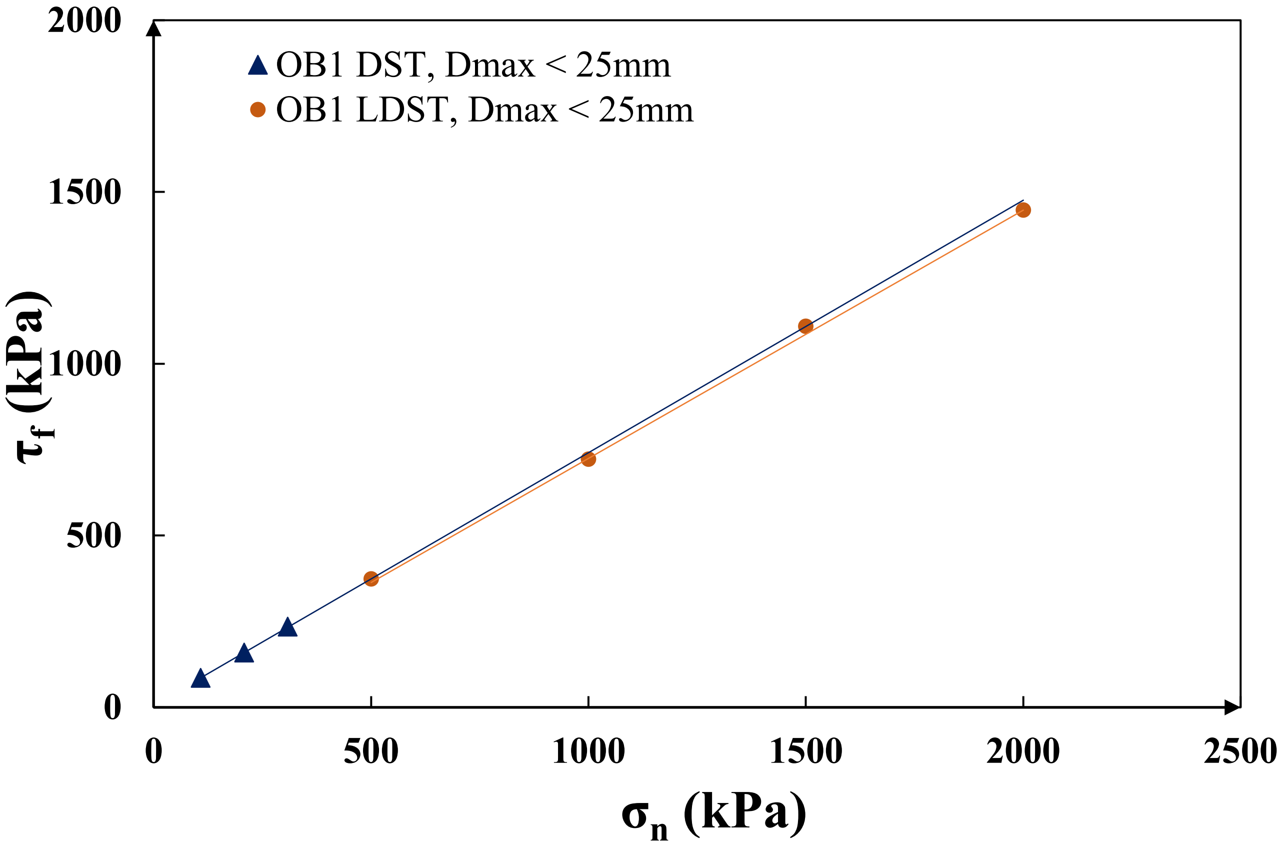


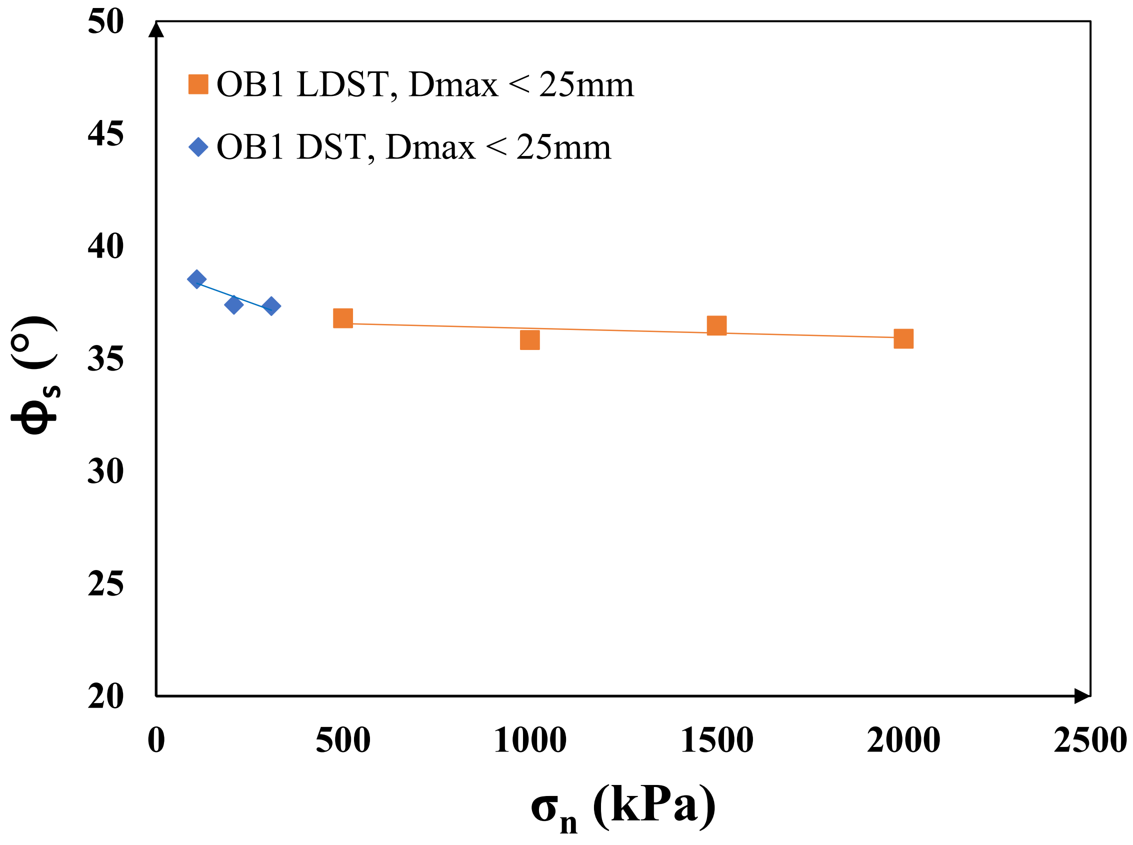
Typical Shear Stress vs Shear Strain Plots



- ✓ All seven OB materials exhibited loose sand or normally consolidated behaviour for all tests, with peak shear strengths (τ_p), reached at horizontal strains (ε) ranging between 3-10%.
- ✓ Distinct peak responses, characterised by a subsequent drop in shear stress, were not clear for most of the normal stresses.
- ✓ At lower normal effective stresses, the peak shear stress prevailed after it was reached
- ✓ In some of the tests where 'stepped' behaviour is evident the frequency of steps diminished prior to reaching the maximum shear stress value and therefore has not affected the test result.

Scale Effect of Box Size Variation Keeping the Same Grains Size

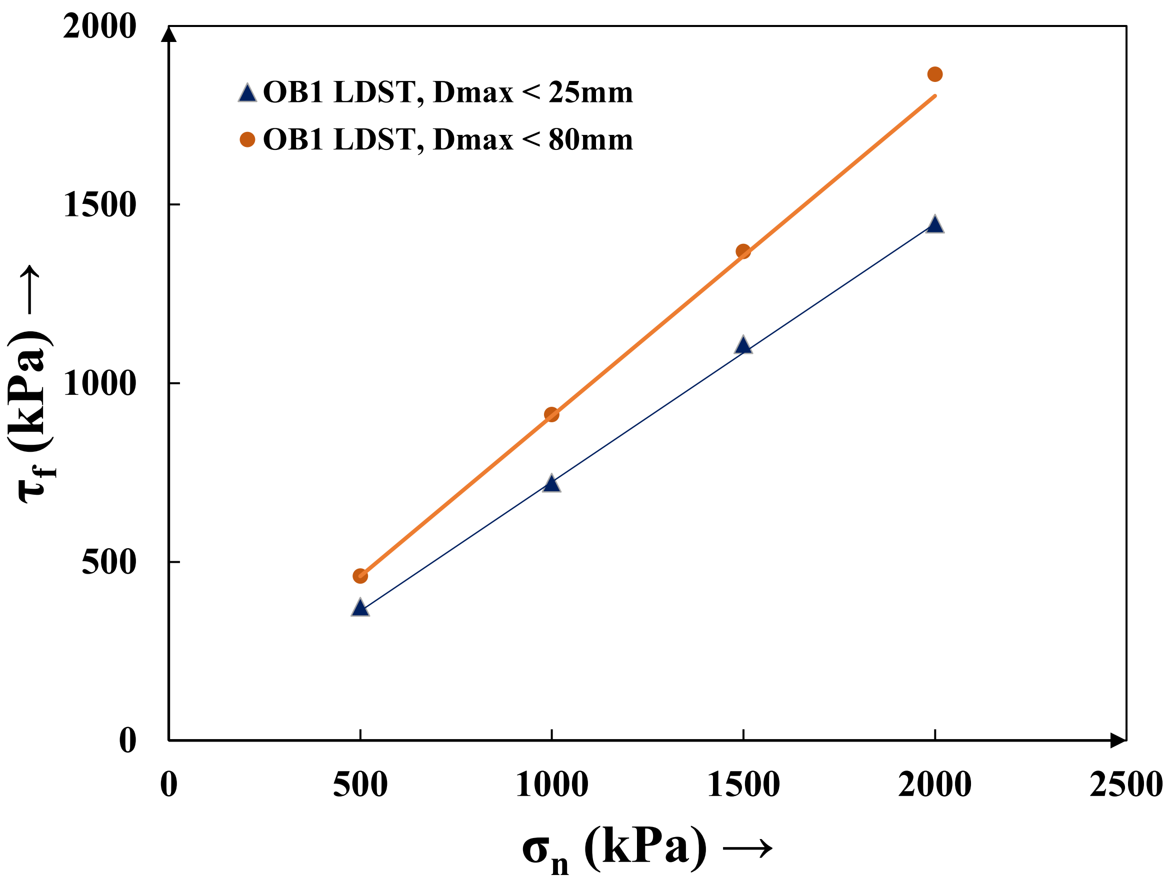


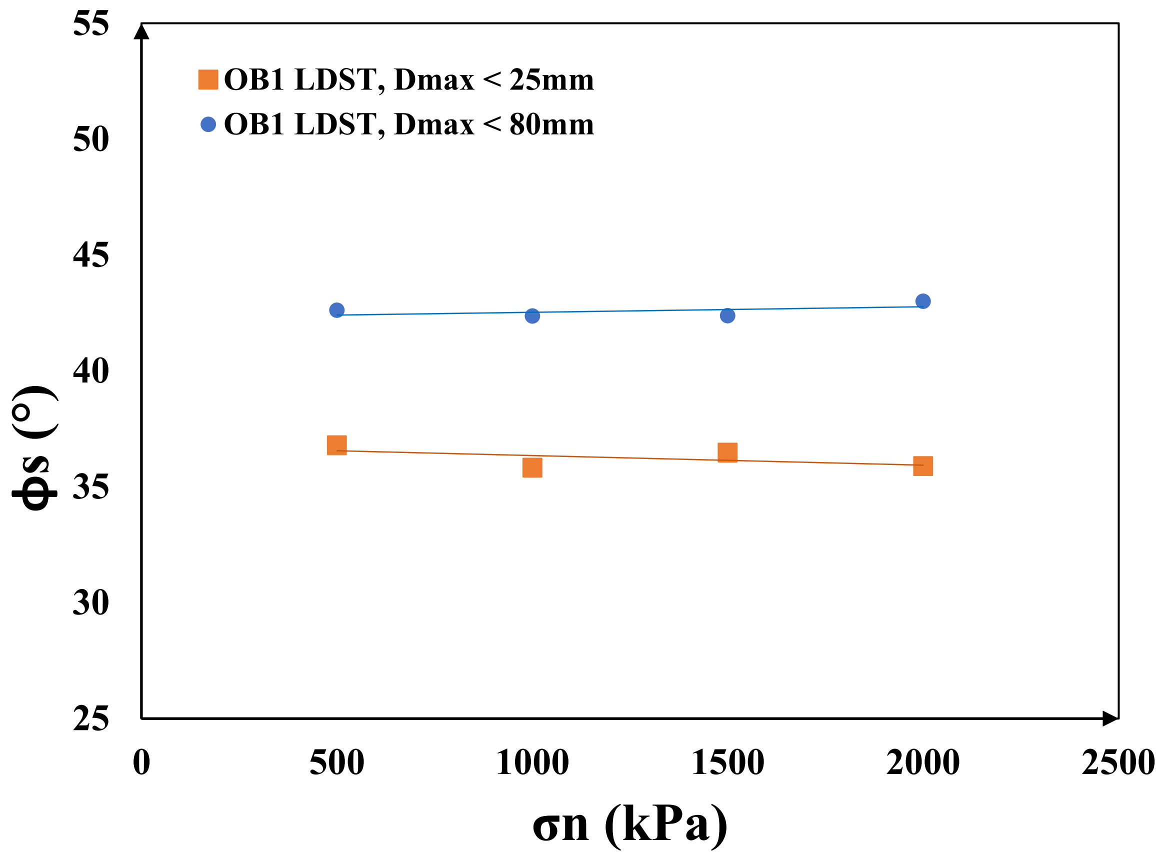


Scale Effect of Box Size Variation Keeping the Same Grains Size

Material	Shear Box (mm×mm)	c (kPa)	φ (°)	Δφ (%)
OB1	300×300	6.6	36.32	
	1000×1000	1.7	35.86	-1.27
OB2	300×300	8.0	36.87	
	1000×1000	4.3	35.88	-2.69
OB3	300×300	2.2	35.75	
	1000×1000	0.3	33.22	-7.08
OB4	300×300	8.3	32.82	
	1000×1000	7.0	32.29	-1.61
OB5	300×300	8.2	33.22	
	1000×1000	3.7	32.81	-1.23
OB6	300×300	5.7	37.95	
	1000×1000	3.0	36.94	-2.66
OB7	300×300	5.2	36.13	
	1000×1000	4.0	35.07	-2.93

Scale Effect of Grain Size Variation Keeping Same Box Size

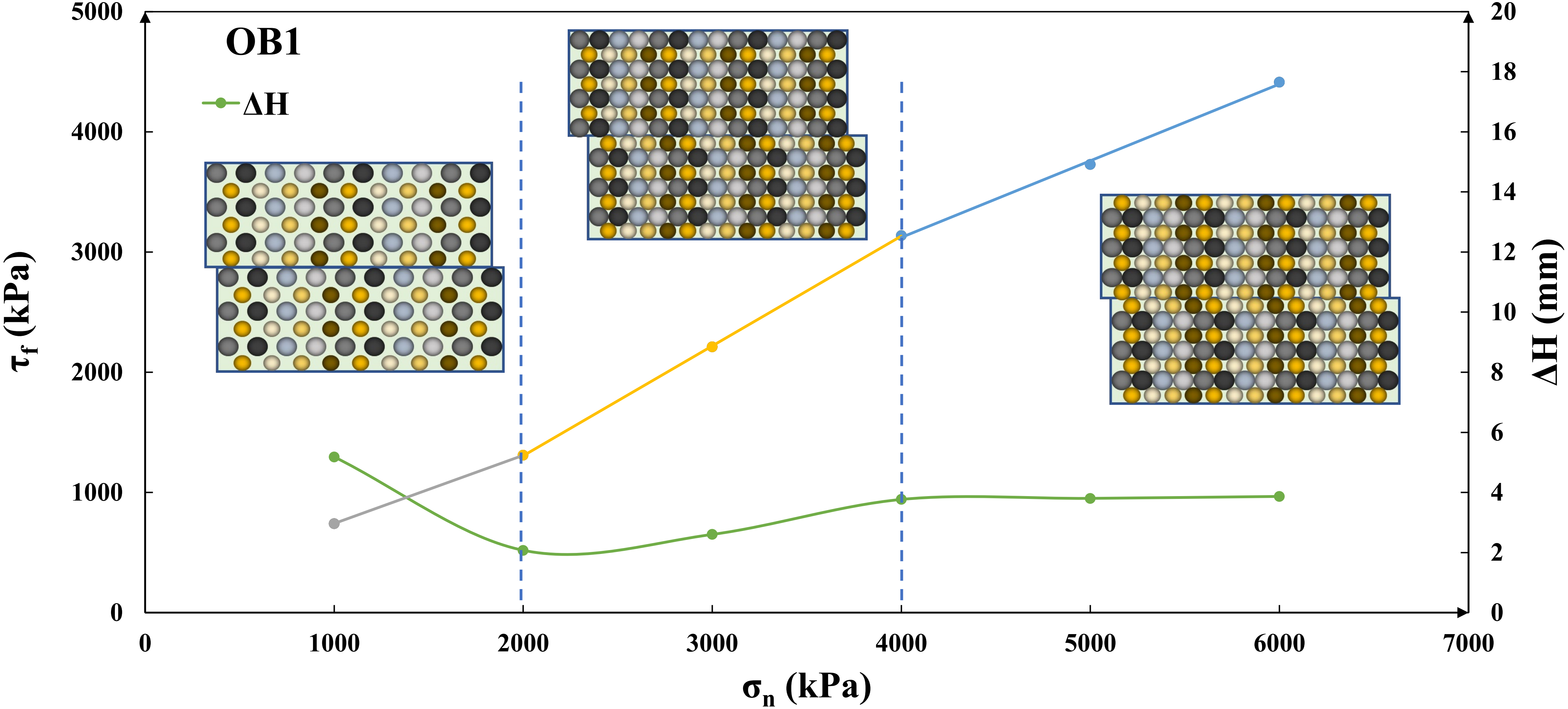




Scale Effect of Grain Size Variation Keeping the Same Box Size

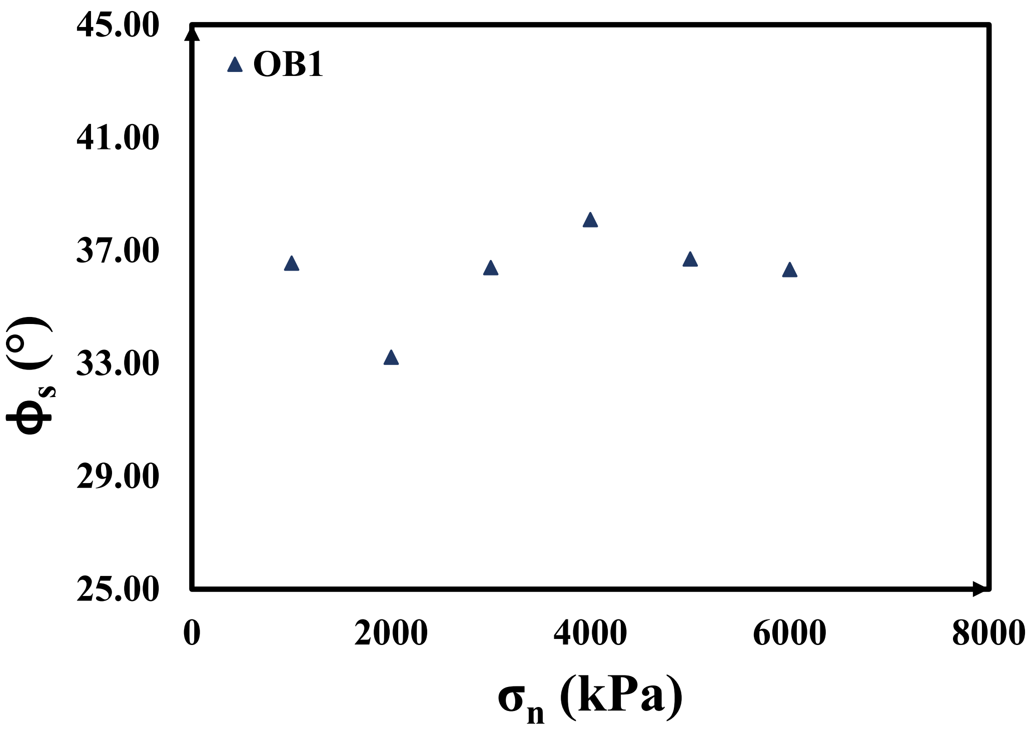
Material	D_{max}	c (kPa)	ϕ (°)	Δφ (%)
OB1	≤ 25mm	1.7	35.86	
	≤ 80mm	12	41.86	16.7
OB2	≤ 25mm	4.3	35.88	
	≤ 80mm	1	40.36	12.5
OB3	≤ 25mm	0.3	33.22	
	≤ 80mm	NA	NA	NA
OB4	≤ 25mm	7	32.29	
	≤ 80mm	2	41.73	29.2
OB5	≤ 25mm	3.7	32.81	
	≤ 80mm	14	43.41	32.3
OB6	≤ 25mm	3	36.94	
	≤ 80mm	7	45.90	24.3
OB7	≤ 25mm	4	35.07	
	≤ 80mm	5.5	40.13	14.4

Scale Effect of Stress Variation



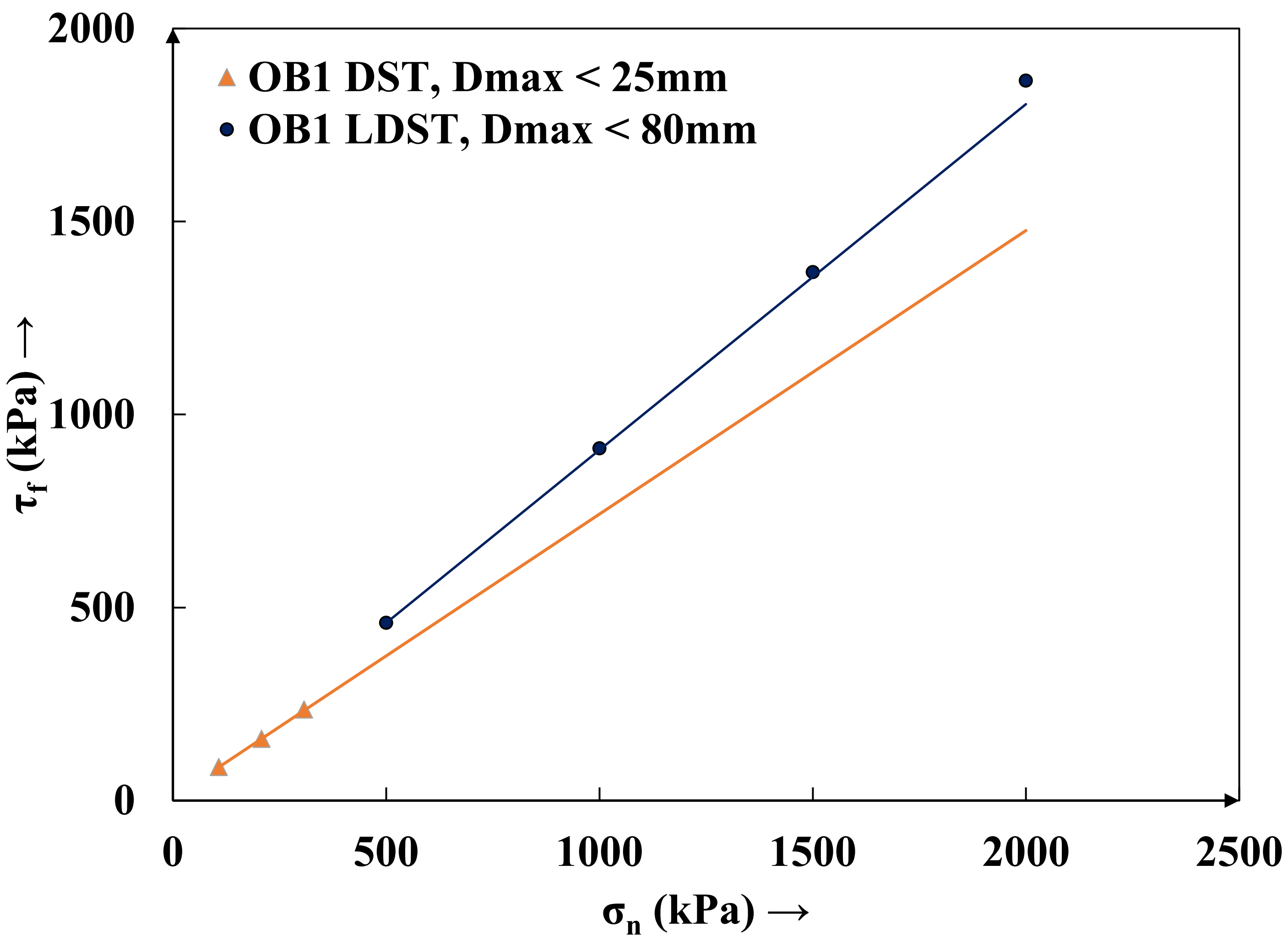
Zone 1:Rearrangement-Sliding, Zone 2:Rubbing –Rolling, Zone 3:Chipping-Sliding

Scale Effect of Stress Variation



	τ_f (kPa)					
σ_n (kPa)	1000	2000	3000	4000	5000	6000
OB1	742	1310	2212	3137	3728	4413
OB2	755	1368	2191	2987	3828	4523
OB3	671	1446	2107	2837	3351	3822
OB4	613	1148	1693	2518	3293	3878
OB5	663	1258	1873	2662	3383	3938
OB6	776	1502	2241	3126	3963	4611
OB7	731	1371	2195	2969	3754	4317

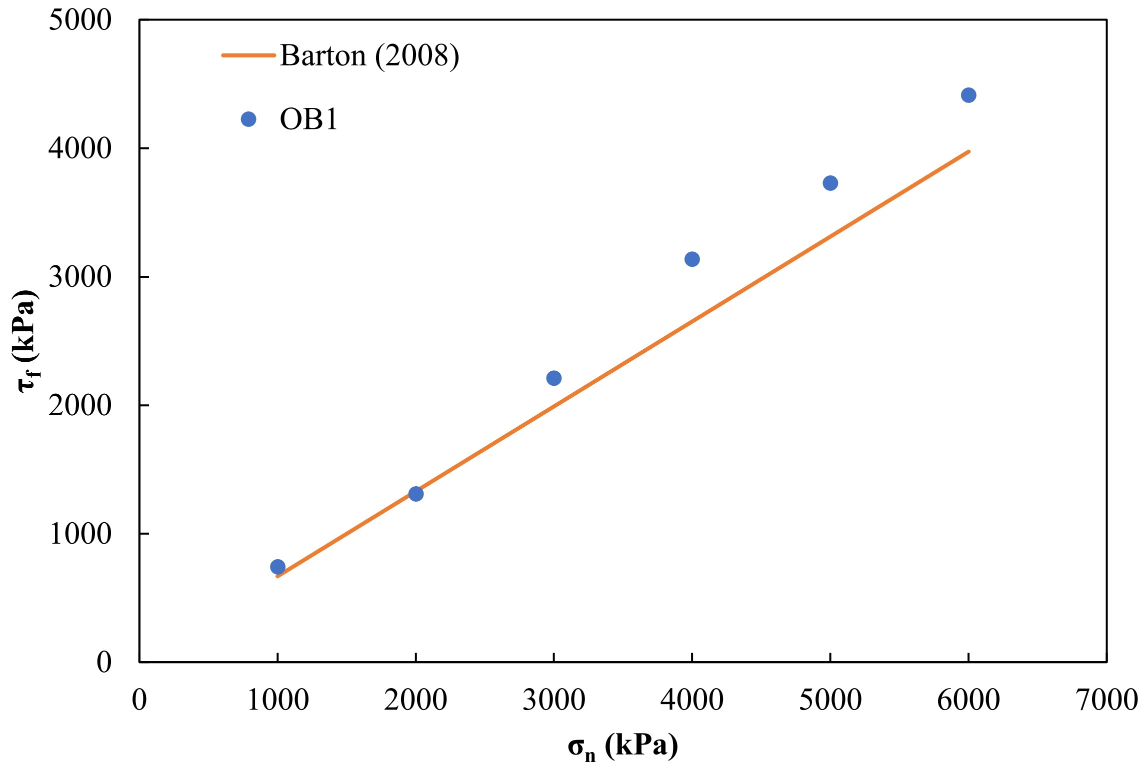
Current Practice (DST, D_{max} ≤25mm) with Proposed Design Practice (LDST, D_{max} ≤80mm)



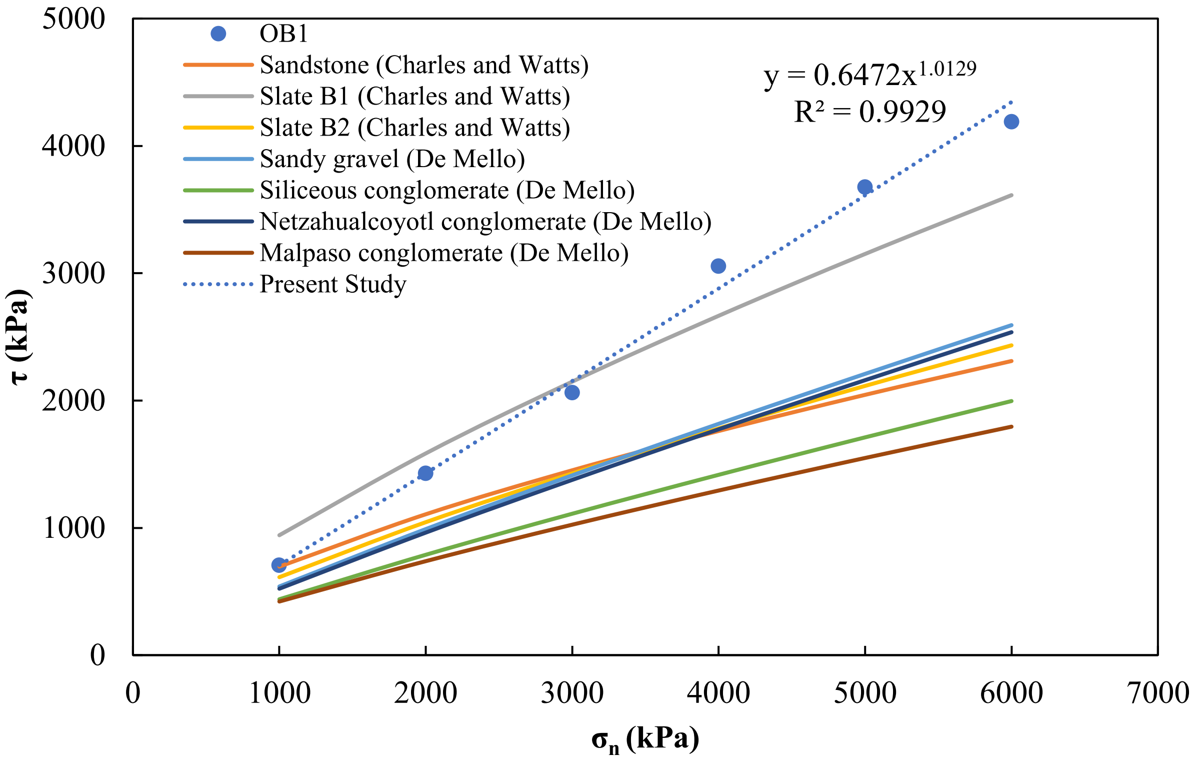
Current Practice (DST, D_{max} ≤25mm) with Proposed Design Practice (LDST, D_{max} ≤80mm)

Material	Test	D_{max} (mm)	c (kPa)	ϕ (°)	Δϕ (%)
OB-1	DST	≤ 25	6.6	36.32	
	LDST	≤ 80	12	41.86	15.25
OB-2	DST	≤ 25	8.0	36.87	
	LDST	≤ 80	1	40.36	9.46
OB-3	DST	≤ 25	2.2	35.75	
	LDST	≤ 80	NA	NA	NA
OB-4	DST	≤ 25	8.3	32.82	
	LDST	≤ 80	2	41.73	27.14
OB-5	DST	≤ 25	8.2	33.22	
	LDST	≤ 80	2	43.41	30.67
OB-6	DST	≤ 25	5.2	37.95	
	LDST	≤ 80	7	45.90	20.94
OB-7	DST	≤ 25	5.8	36.13	
	LDST	≤ 80	5.5	40.13	11.07

Regression Analysis and Empirical Relation



Mohr-Coulomb Failure Data for OB-1 Tests, Compared with Barton's Empirical Failure Envelope.



OB-1 Test Data, Compared with Power-Law Failure Envelopes for Similar Rocks

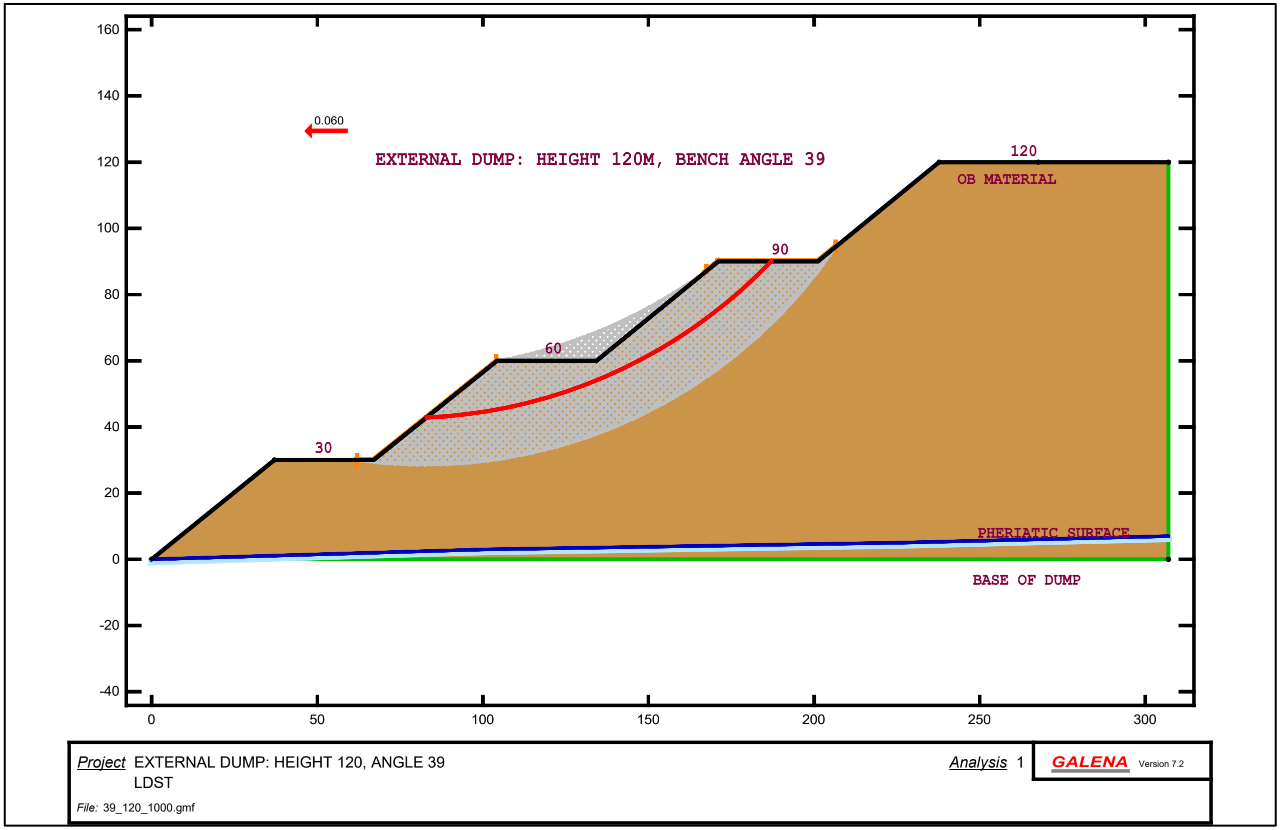
Stability Analysis of OB Dumps

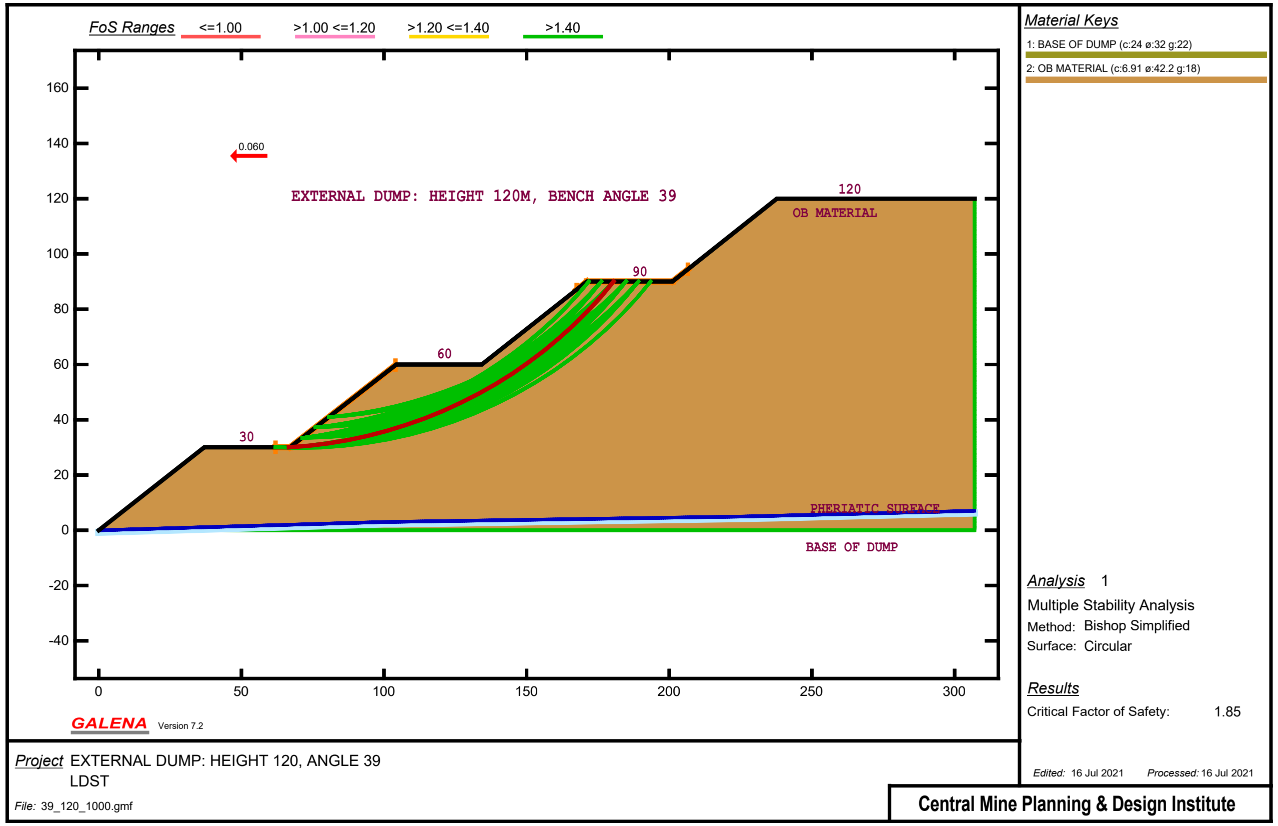
Cases Considered for Stability Analysis

Type of Dump	Height (m)	Bench angle	Strength Properties
External dumps	90, 120, 150	37.5°, 39°, 40°	DST and LDST
Internal dumps	150, 180, 210, 240	37.5°, 39°, 40°	DST and LDST

- ✓ A total of 42 models of dumps sections of internal and external dumps were prepared during the analysis which are labelled as M1 to M42.
- ✓ Models prepared for certain bench angle and overall height then same modelled is analysed for strength properties from DST and LDST.
- ✓ Further each model is varied based on failure surface assumption i.e. for local and global failure.
- ✓ Finally factor of safety (FoS) for critical failure circle and probability of for the critical failure surface were carried out for local and global failures.

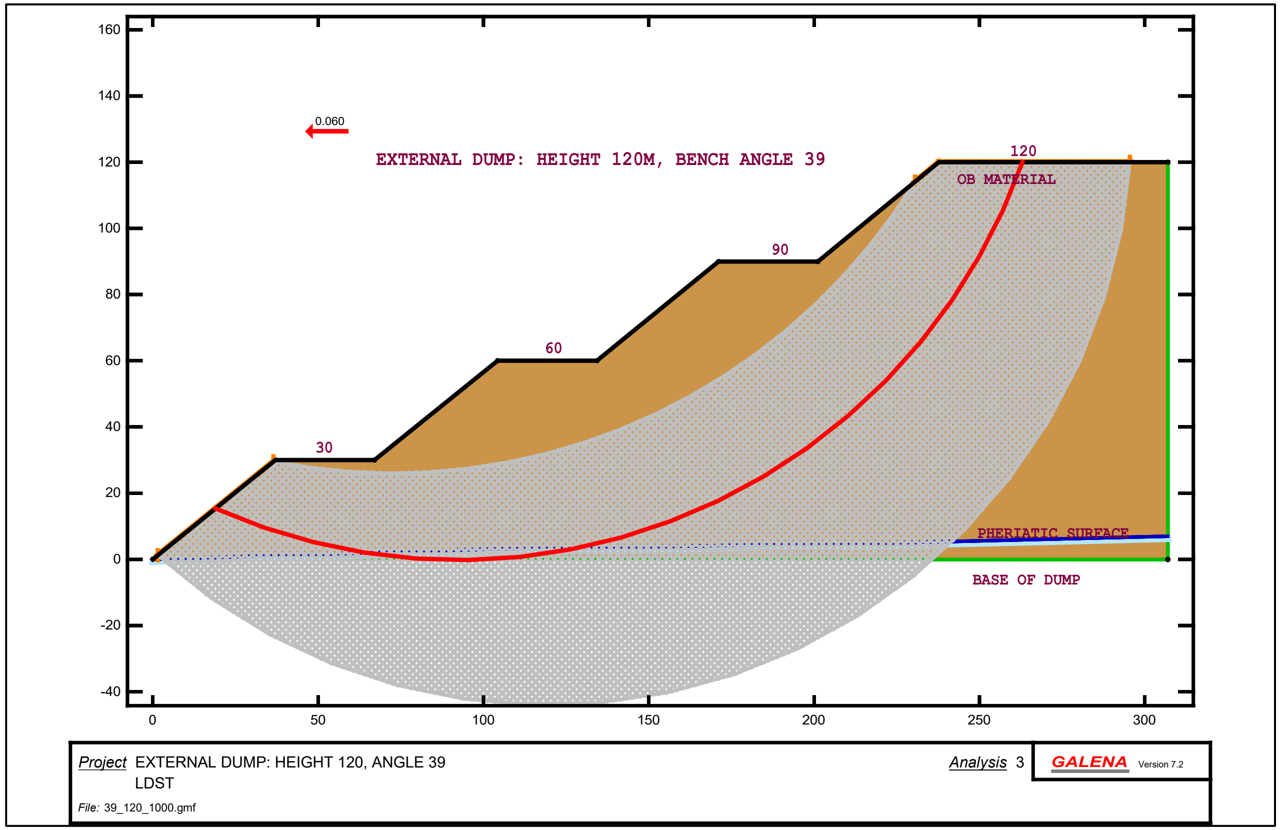
Model 10: External Dump, height 120m, Bench angle 39, analysis using LDST data

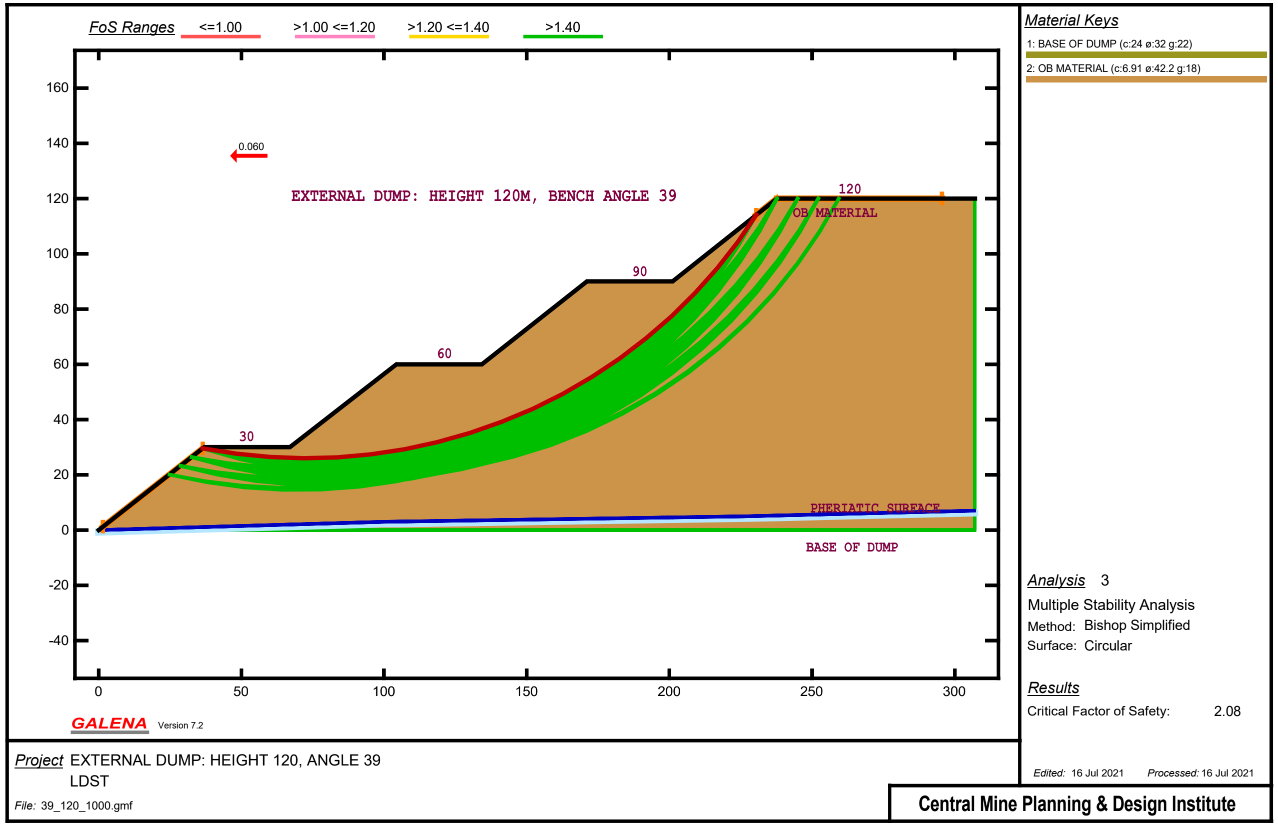




Analysis for Local Failure

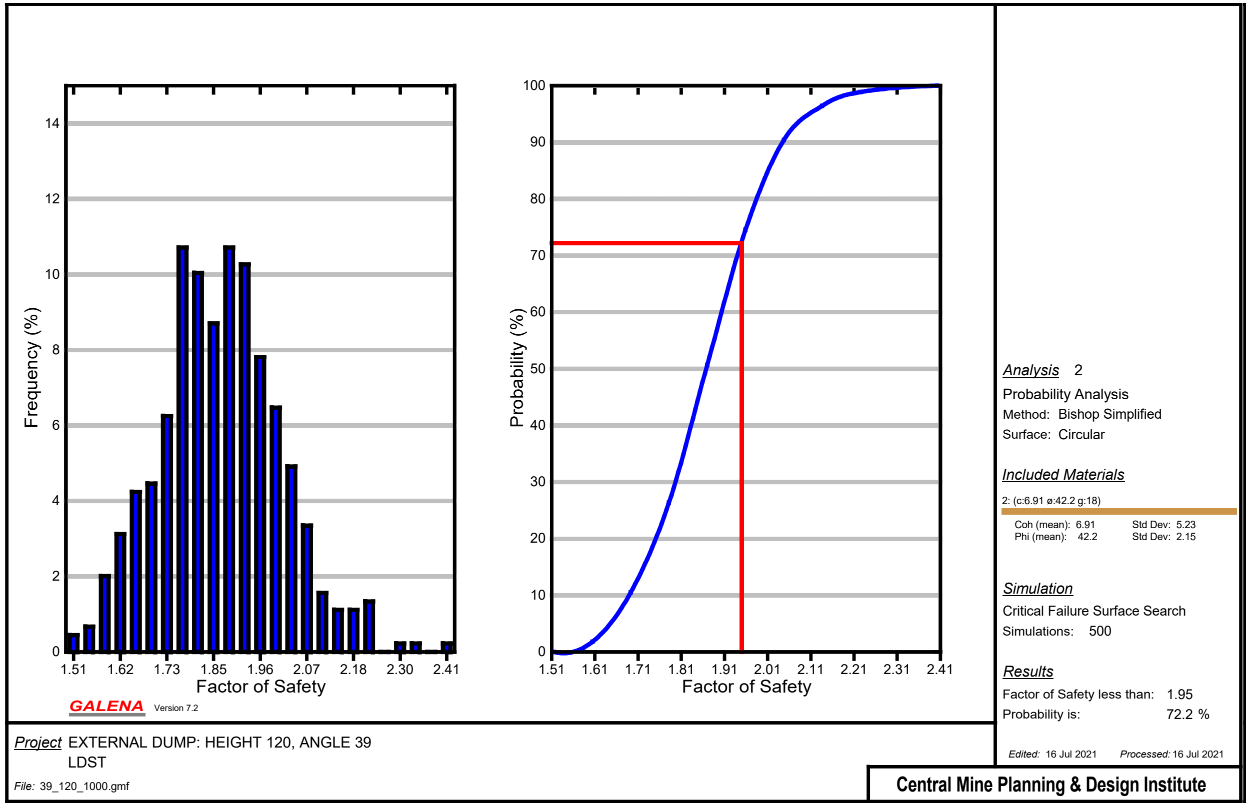
Model 10: External Dump, height 120m, Bench angle 39°, analysis using LDST data



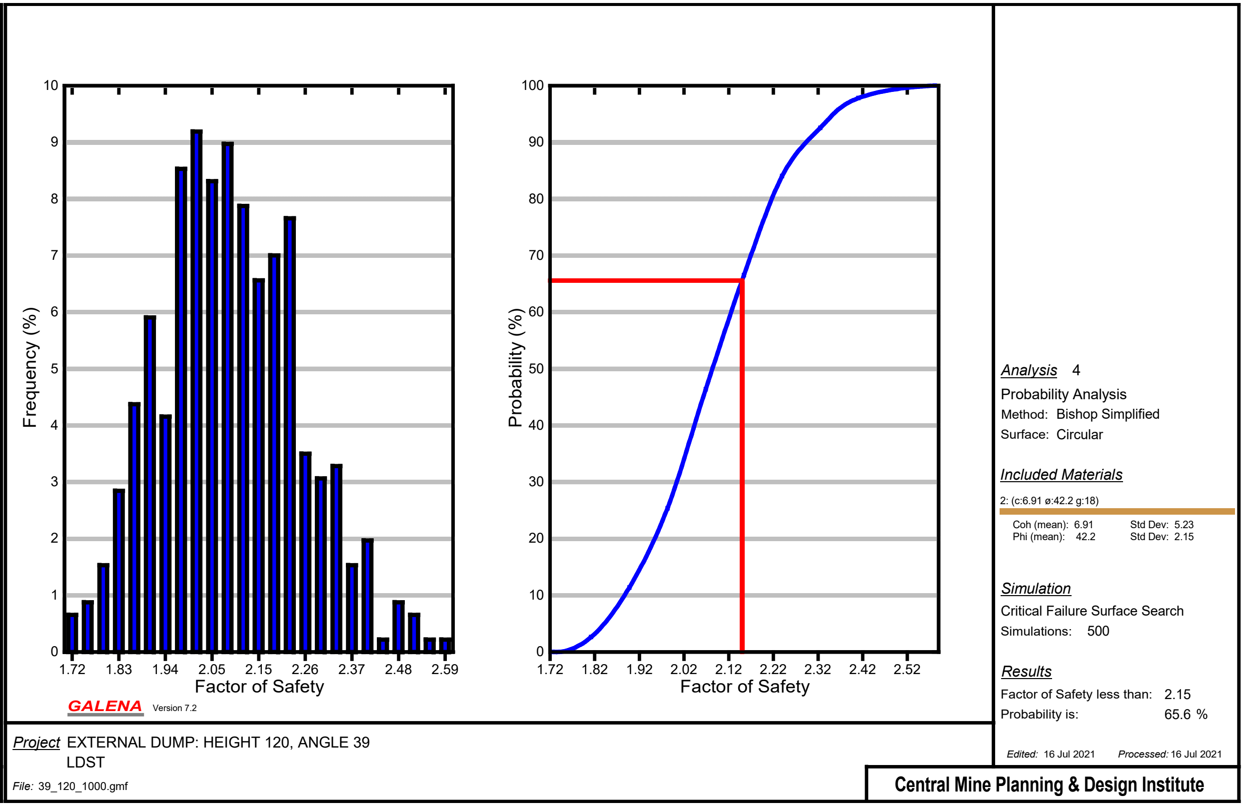


Analysis for Global Failure

Probability Analysis - Model 10

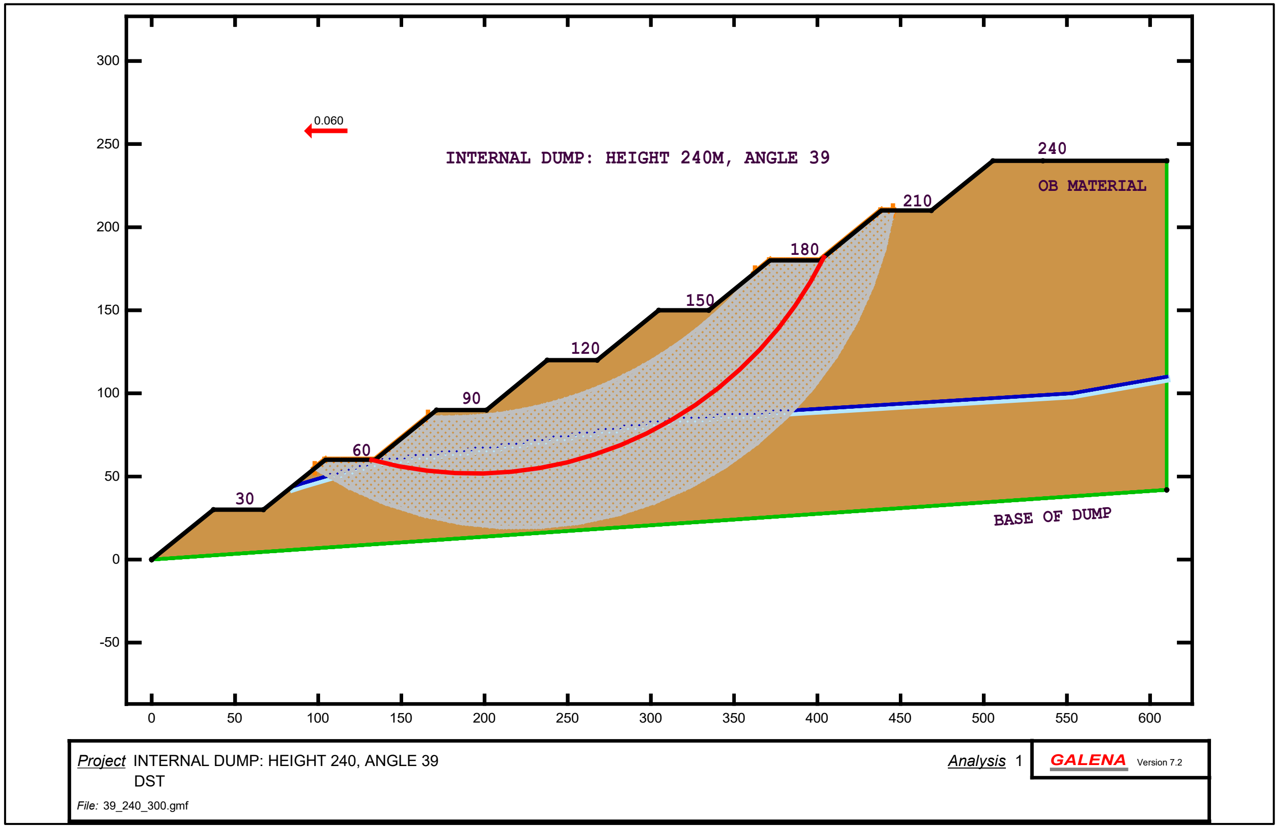


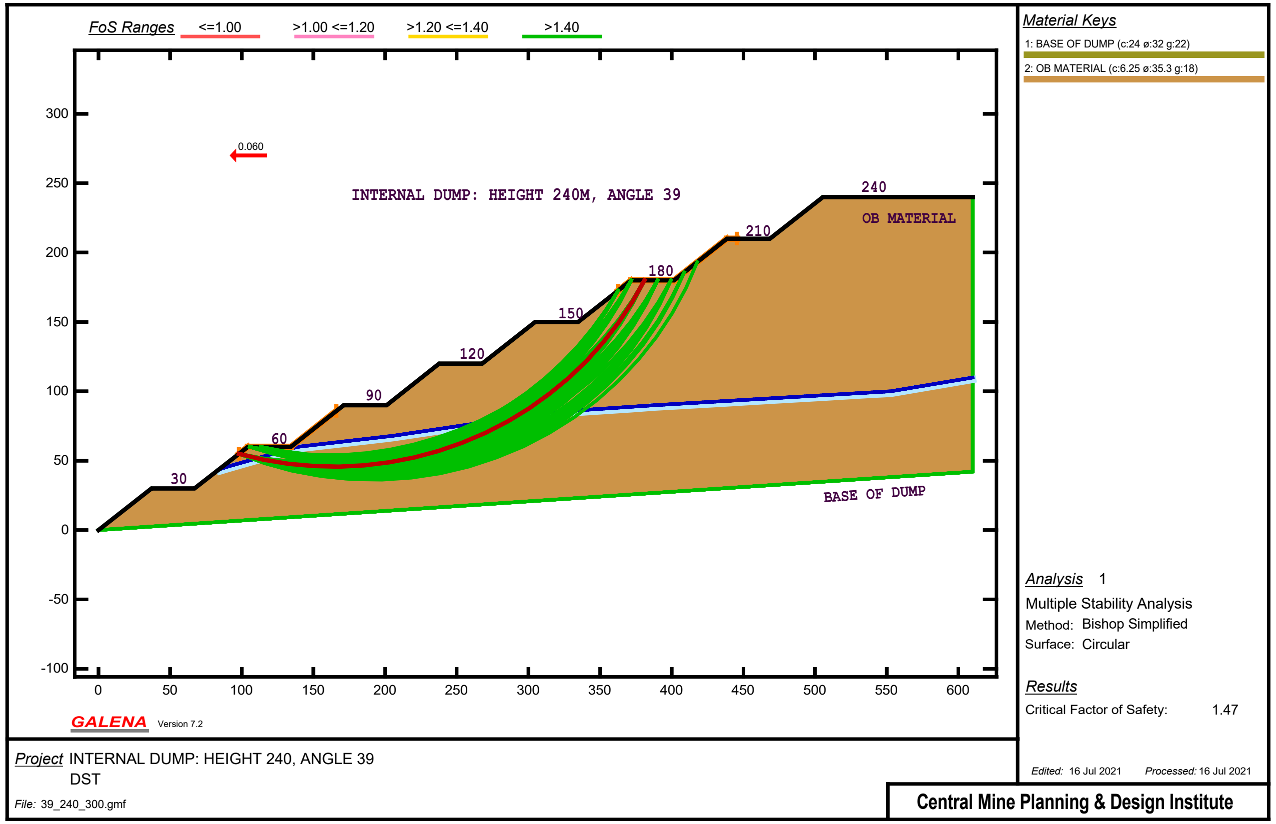
Probability Analysis for Local Failure



Probability Analysis for Global Failure

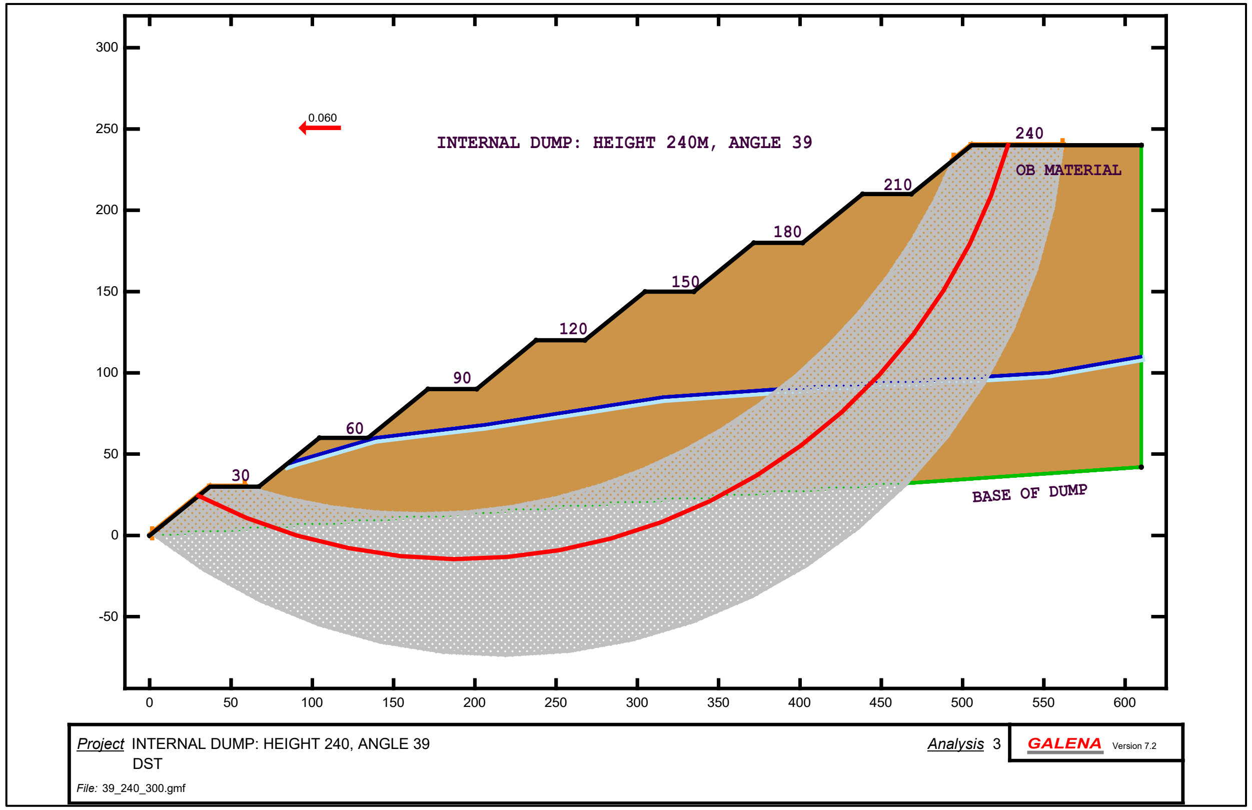
Model 33: Internal Dump, Height 240m, Bench Angle 39, analysis Using DST Data

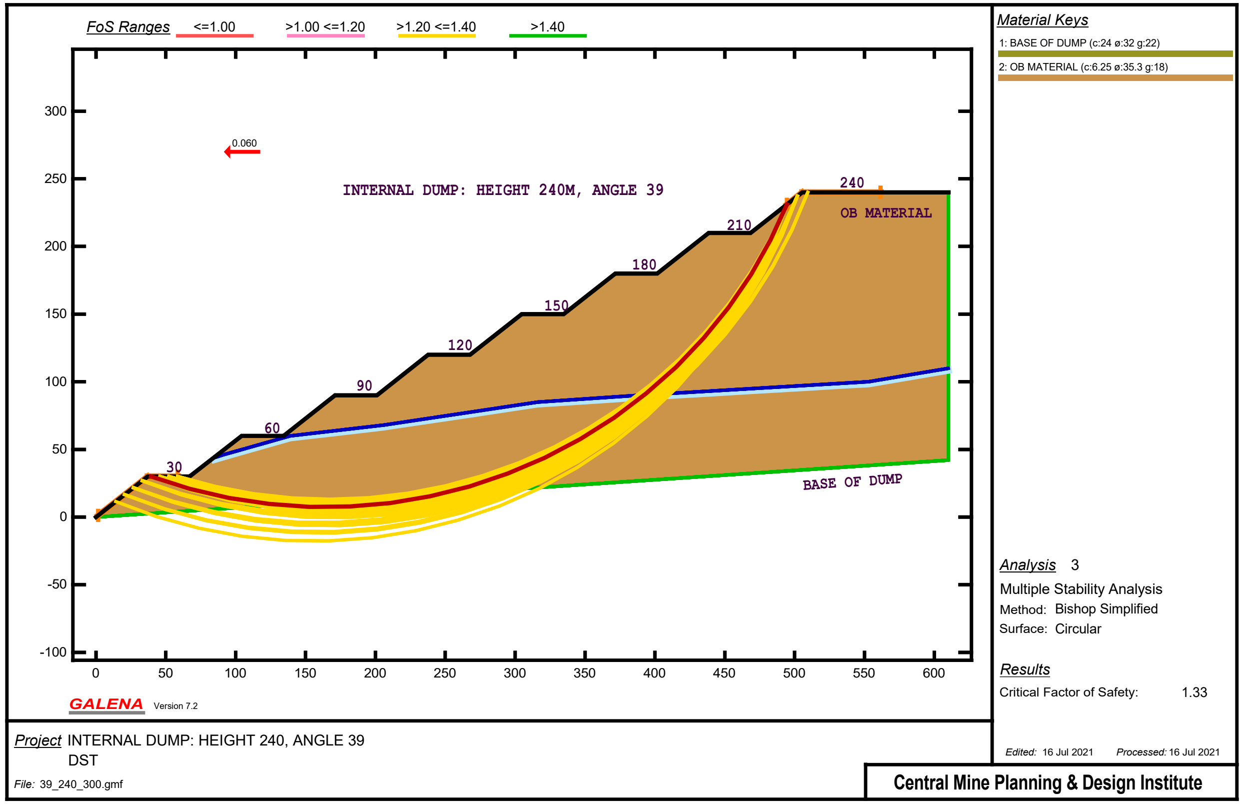




Analysis for Local Failure

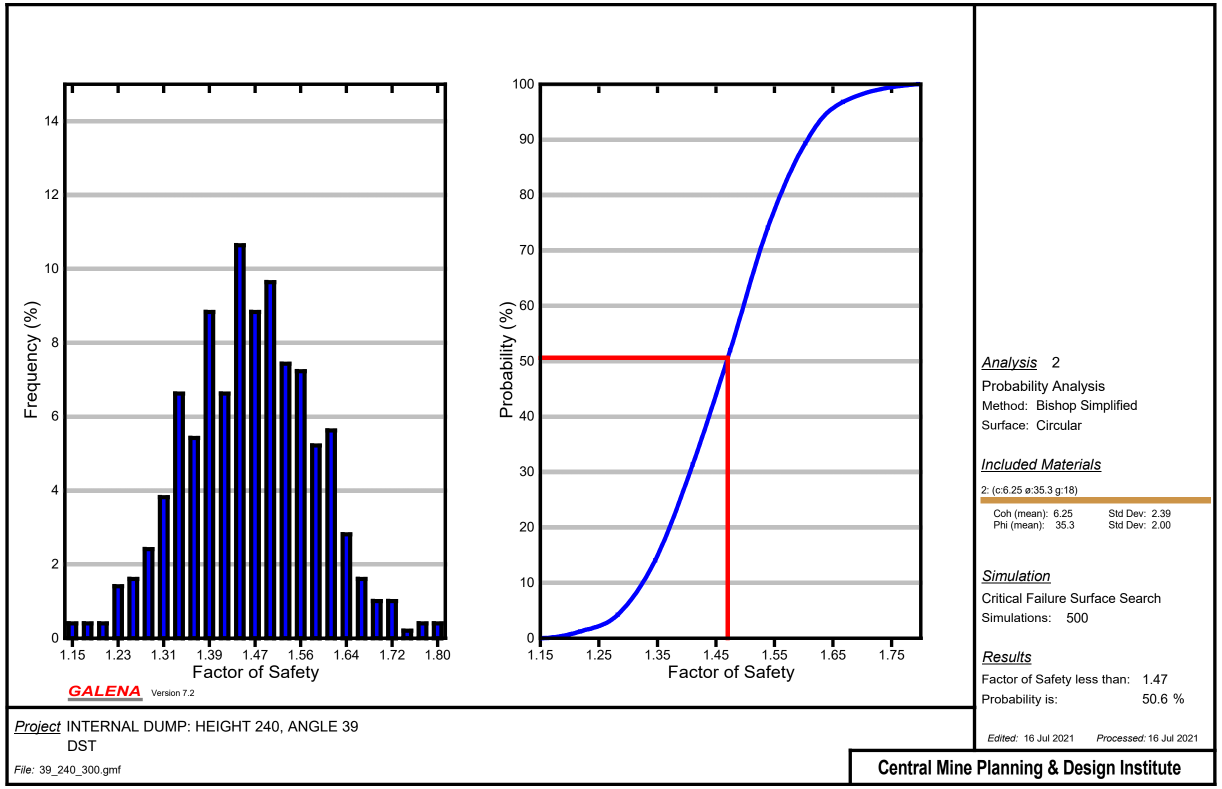
Model 33: Internal Dump, Height 240, Bench Angle 39�, Analysis Using DST Data



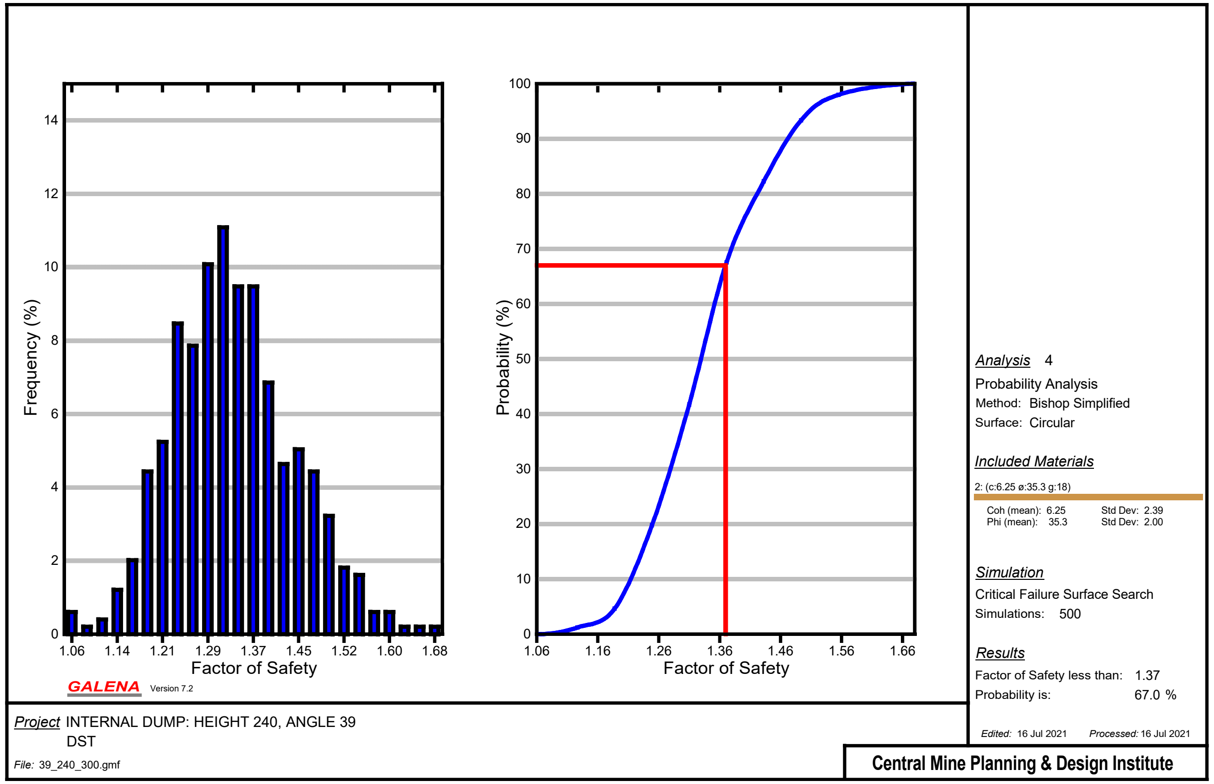


Analysis for Global Failure

Probability Analysis - Model 33

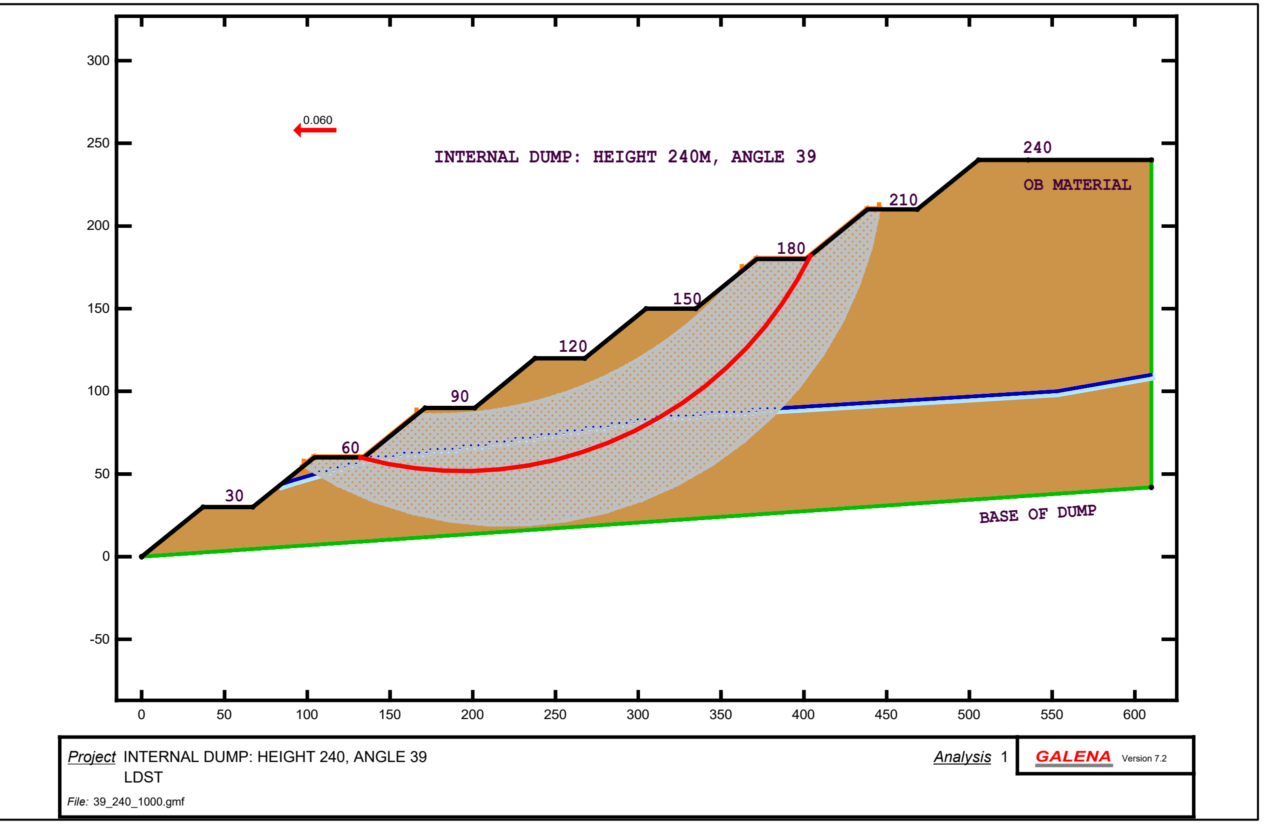


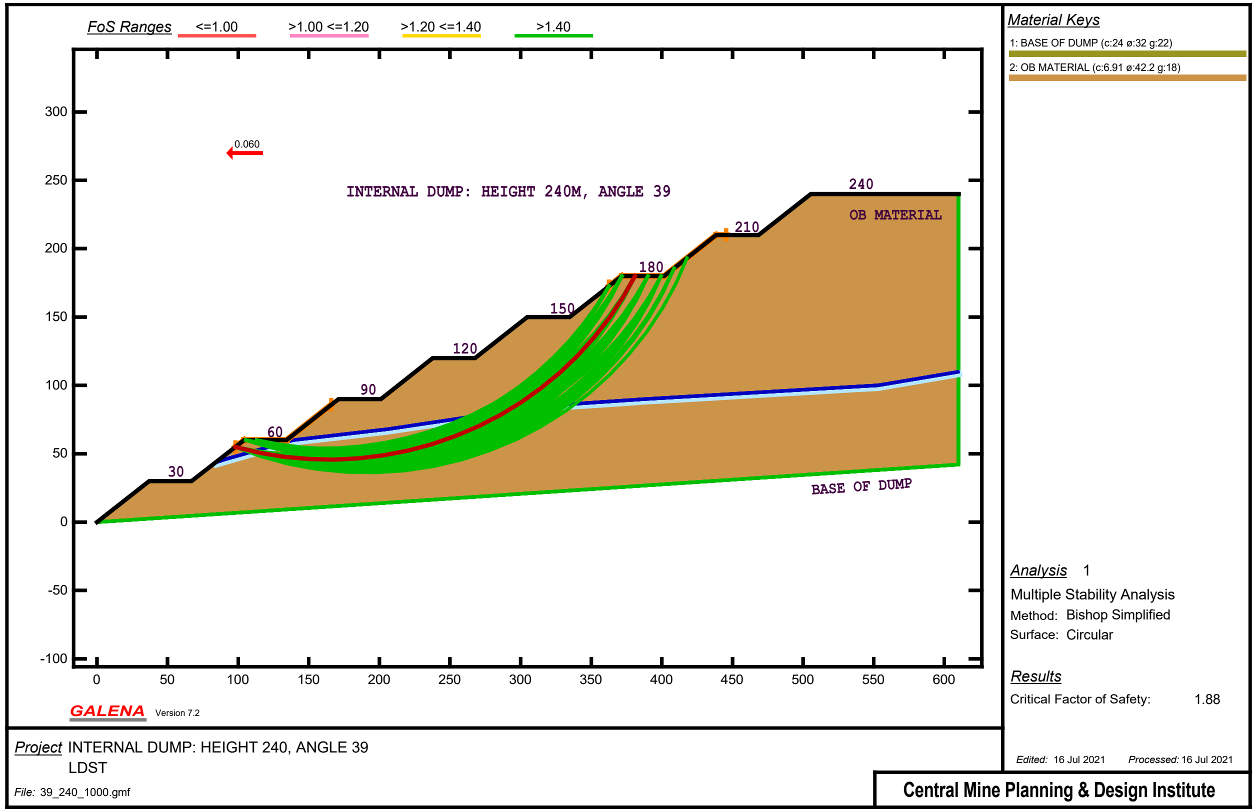
Probability Analysis for Local Failure



Probability Analysis for Global Failure

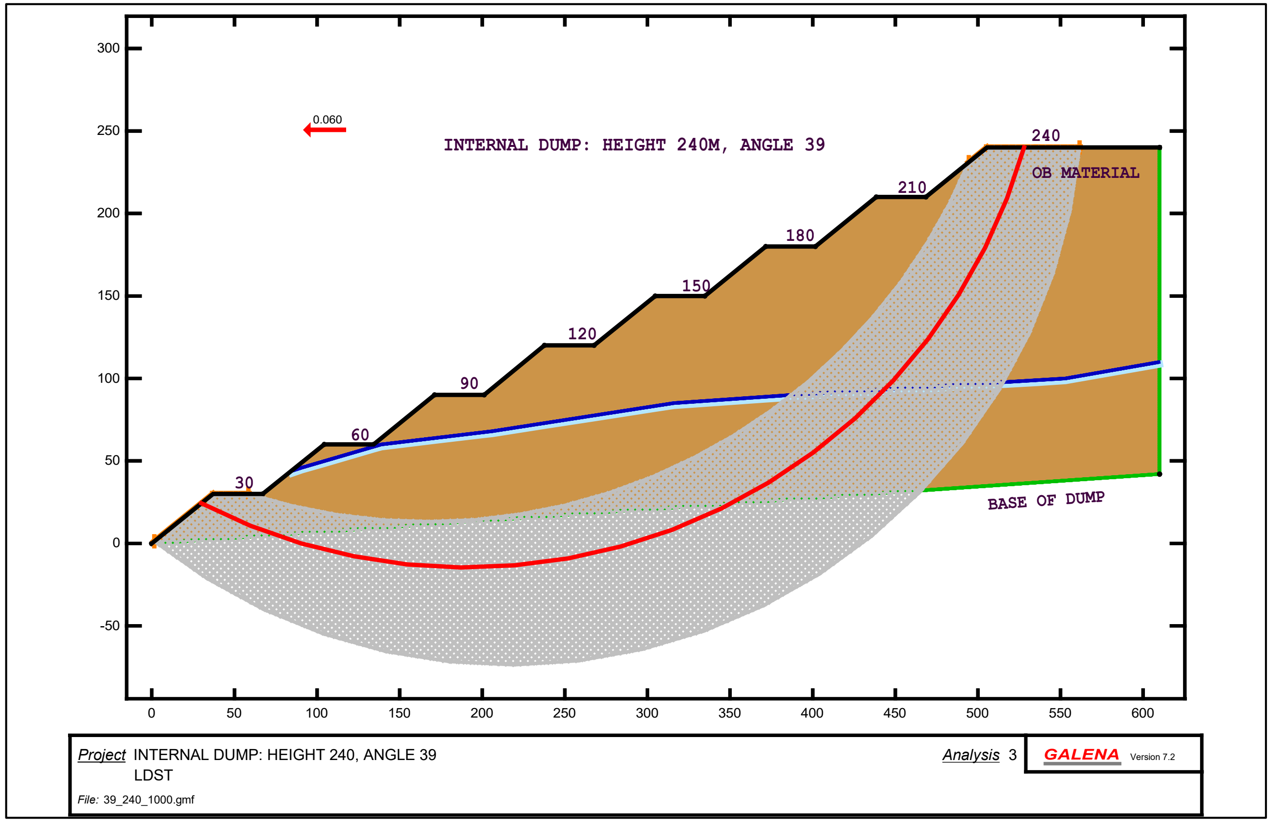
Model 34: Internal Dump, Height 240, Bench Angle 39�, Analysis using LDST data

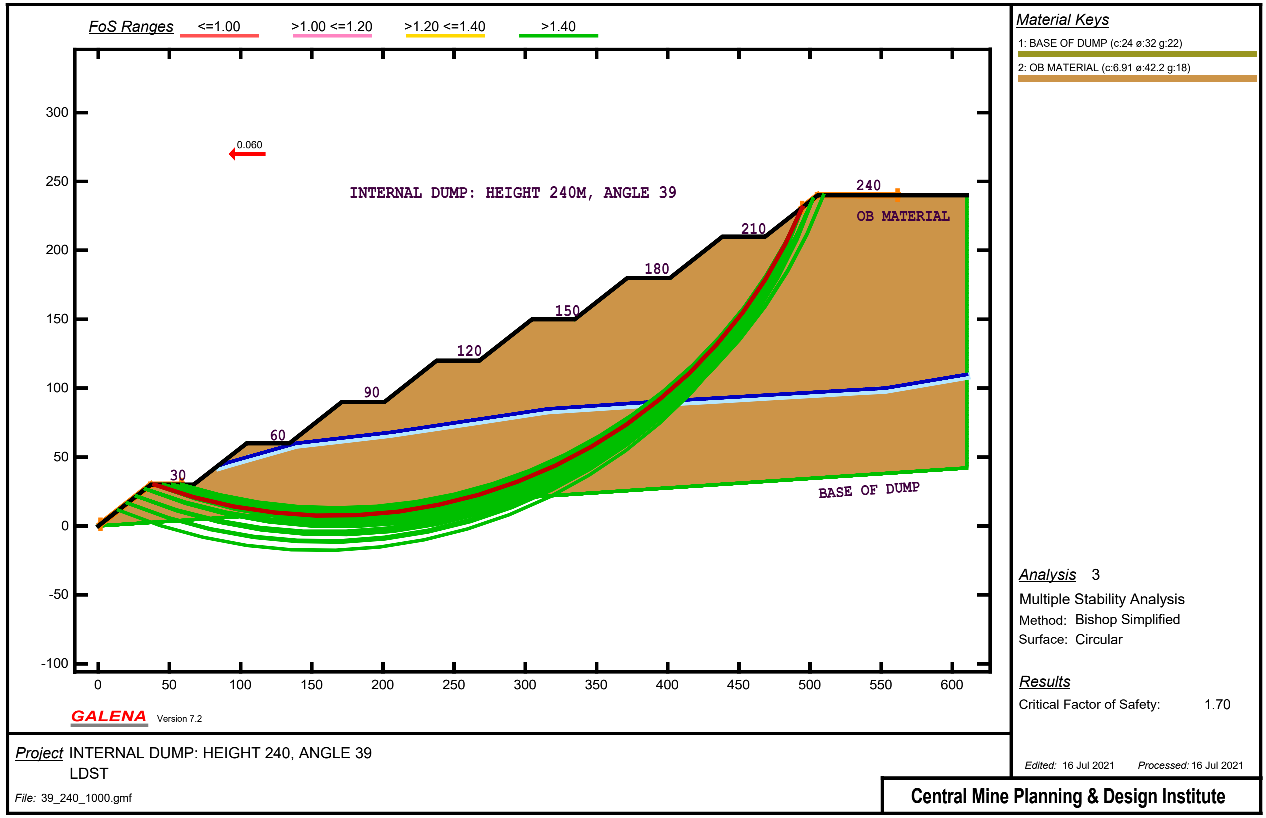




Analysis for Local Failure

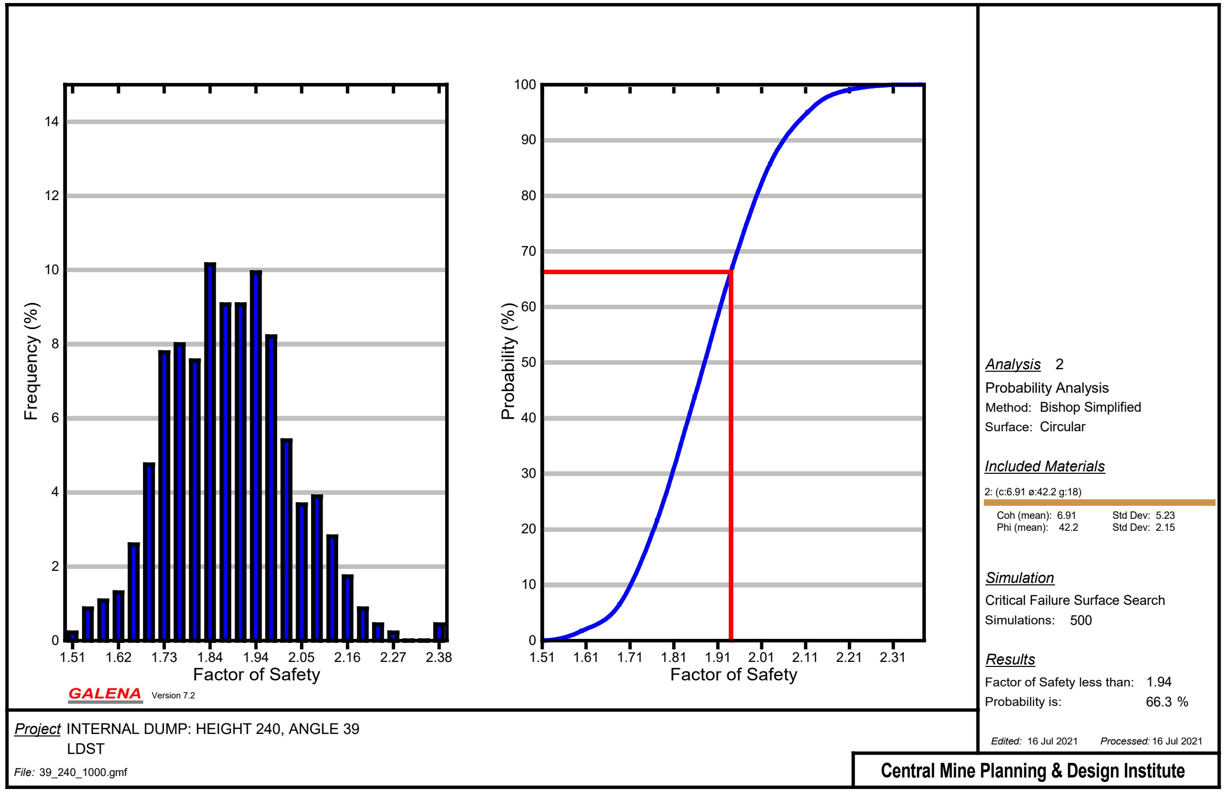
Model 34: Internal Dump, Height 240, Bench Angle 39�, analysis using LDST data



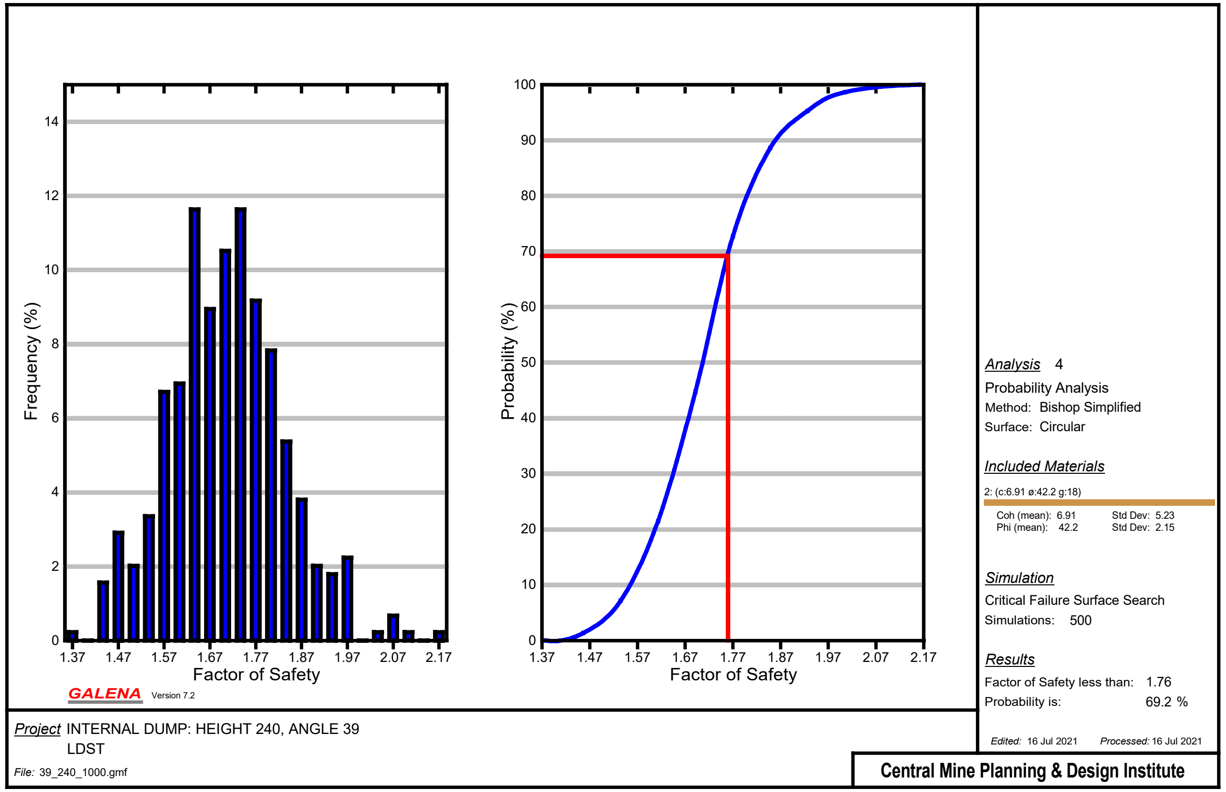


Analysis for Global Failure

Probability Analysis - Model 34



Probability Analysis for Local Failure



Probability Analysis for Global Failure

Variation of FoS with Varying Bench Angle and Dump Height

Bench Angle (°)	Height of Dump (m)	Box Size (mm×mm)	Min	Max	Mean	Δchange (%)	SD
35	120	300×300	1.33	2.13	1.74	27.01	0.132
		1000×1000	1.0	2.76	2.21		0.181
	240	300×300	1.33	1.97	1.64	29.88	0.121
		1000×1000	1.64	2.60	2.13		0.164
37	120	300×300	1.35	2.22	1.73	26.59	0.126
		1000×1000	1.0	2.69	2.19		0.198
	240	300×300	1.29	1.95	1.58	27.85	0.122
		1000×1000	1.63	2.47	2.02		0.151
39	120	300×300	1.34	1.96	1.63	27.61	0.116
		1000×1000	1.64	2.56	2.08		0.157
	240	300×300	1.21	1.85	1.51	27.81	0.107
		1000×1000	1.48	2.40	1.93		0.148
41	120	300×300	1.23	1.96	1.54	28.57	0.116
		1000×1000	1.56	2.62	1.98		0.147
	240	300×300	1.17	1.82	1.47	27.21	0.111
		1000×1000	1.50	2.37	1.87		0.131

Conclusions

1. A significant achievement of the research was the successful design, development and operation of the large direct shear machine (LDSM) and its subsequent application to provide reliable design information for current and planned very-high dumps.

2. The LDSM is able to test at a much larger scale, in terms of combined specimen size and stresses, that has ever previously been achieved using a direct shear machine for geotechnical testing of OB dumps.

3. LDSM has a stable and robust shear box suitable for testing of sample of size of up to 1000mm×1000mm×1000mm. It has a loading/reaction frame that consists of two servo controlled hydraulic actuators capable of applying normal and shear load upto 2500kN.

4. A smaller shear box assembly is also made with shear box of 300mm×300mm×300mm size with the capacity to hold upto 10MPa normal load.

Conclusions

5. Through geotechnical characterization, it is observed that particle size ranging from 25mm-80mm is present in abundance. It contributes approximately 50% of the mass of OB dump material of $D_{max} \leq 80mm$ which, in general, classify OB dump material as coarse gravel.

6. The scale effect on shear strength implies that there will be a minimum DSM size, in terms of both specimen/shear box volume and load capacity, that can be considered technically acceptable for simulating a shear surface within a OB dump.

7. The shear strength parameters for regular laboratory test in DSMs tend to over estimate the shear strength slightly higher over the similar material in LDSMs.

8. OB materials direct shear test results show that the friction angle is scale-dependent variable in terms of particle size and shape.

Conclusions

9. For materials differentiated only by D_{max} (here, $D_{max} \leq 25$mm and $D_{max} \leq 80$mm), friction angle has increased significantly upto ~33° which infers that higher particle size contributes to formation of clast around large size particle along shear plane resulting into higher shear strength.

10. Well graded OB materials with presence of angular particle to sub angular particles have higher mechanical potential for better interlocking which results into higher shear strength.

11. Clast strength inadvertently determines the transition stress at which particle repacking stops (Zone 1) and particle breakage commences (Zone 2). Clast strength also determines when whole-scale crushing during compression occurs at high stress (Zone 3). Thus, clast strength could be used to approximate the shearing mechanism for a given normal stress.

12. Reliable estimation of shear strength using continuous functions could only be made within limited ranges of normal effective stress.

Conclusions

13. Coal Mine Regulation (CMR – 2017, sub-regulation 106) limits the individual bench angle to 37.5° but stability analysis using reliable parameters from LDST suggest that steeper bench angle beyond 37.5° upto 41° can also be considered safe.

14. This research also resolves uncertainties regarding shearing behaviour of contemporary and planned OB dumps up to 250m in height (high stress) and provides advice on determining reliable shear strength parameters for geotechnical design.

15. Test result shows that current practice of estimation of shear strength parameters using $D_{max} \leq 25mm$ underestimates the strength properties of OB materials and FoS of dumps considerably.

16. DGMS insists for a minimum FoS of 1.5 for permanent long standing pit and OB slopes and a minimum FoS of 1.3 for temporary slopes. The results obtained from LEM analyses show that the optimised slope gives a FoS of more than stipulated FoS by DGMS. Hence, the storage capacity of the dump can be enhanced without compromising on its stability by way of accommodating more OB for a given base area.

17. Need is the "Boulder Mechanics"

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Thank You For Attention

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