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Flexible Shed Tunnel An Innovative Solution for Rockfall Mitigation near Tunnel Approach

Arghadeep Dasgupta

Abstract: Hazards provoked by released rocks and slides due slope instabilities from loose, disintegrated and weathered surfaces in potentially risky areas often occur and are able to cause considerable damages to human beings and infrastructure.
Continuous shooting stones at the crown portion of the tunnel and adjoining slopes under study poses a considerable risk to the infrastructure at the site and livelihood, hence it should be adequately protected with appropriate mitigation systems with flexibility in installation and maintenance owing to the remoteness of the terrain.
Thus necessity of an eco-friendly protection system rises, which acts in an efficient and reliable barrier, being based on high resistant components and will act as aresilient unit.

Key Words: Flexible Shed Tunnel, FST, tunnel shed, rockfall barrier, trajectory movement etc.

Introduction: Therailwaybuiltinmountainareaoftenadopttunnel-bridge-tunneltopassthroughvalley.Thetwosidesofbridgeinhighmountainsanddeepvalley,with complicatedgeological condition and in the sites where protection requirement is relatively high, especially when protecting bridge surface and portal, flexible shed tunnel is usually adopted.
Flexible shed tunnel sets steel structure frame as the main structure and pave flexible protection net as Rockall protection layer. Therefore, the shed tunnel has the characteristics softness of steel structure and flexibility of flexible protection net, fully utilizing the feature of overcome fineness by softness".

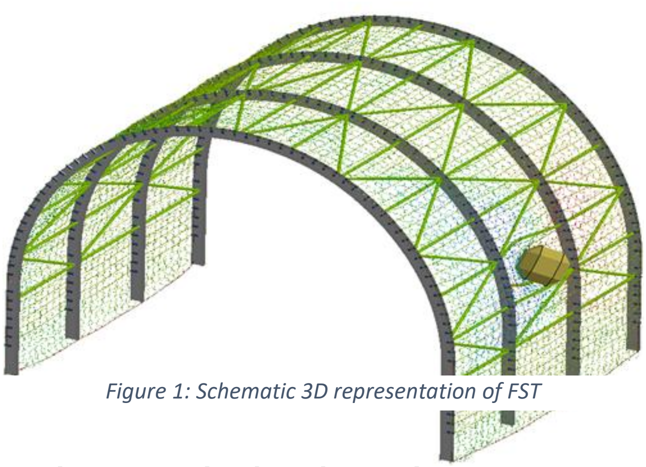

Figure 1: Schematic 3D representation of FST

Flexible sheds are common measures to protect roads and railways from Rockfall events. Rockfallis one of the most relevant natural hazards in the mountainous regions which usually develops fromsteepslopes. Protection shed galleries are preferred when the area that has to be protected is narrow and well limited, like roads and railways, and safety in the area is of highimportance.
Flexible tunnel sheds are proposed at entry and exit of several tunnels. The Scheme consists of ribs in Structural Steel whose main members placed @ 3.0m center to center. The portals are connected by tie beams & bracings to ensure the lateral stability and in order to protect the rock fall events from hill slope, portals are covered with meshes, steel wire ring net, DT mesh, steel chain link mesh. The design capacity of the flexible rock fall shed is 550 KJ.

Tunnel No	**5**	**Portal No.**	**2**

Surface of the location above the tunnel is treated with shot Crete. Fractured rocky strata of shale / silt stone structure is observed at the zone to be protected. There are alternative bands of dark and yellow sandstone and shale. The rock joint spacing is between 2.0 and 2.5m. The source zone is at almost weathered condition and has chip like structures. Multiple number of sources are observed at height 21 – 22m height from the tunnel ground level. The severity of the source zone ranges from moderate to major.

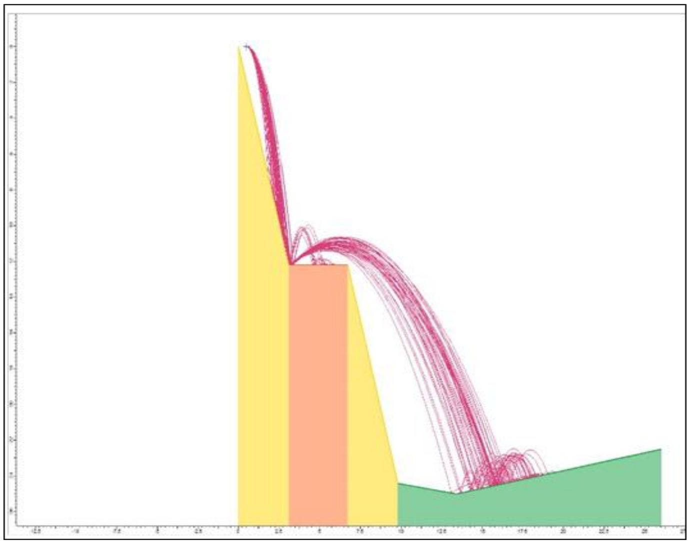

Figure 2: Rock movement modelling in Rockfall software

S No	Length (m)	Breadth (m)	Height (m)	Volume (m^3)
1	1.27	0.78	0.56	0.554
2	0.23	0.26	0.32	0.019
3	0.145	0.23	0.12	0.004
4	0.23	0.335	0.24	0.019

Table 1: Illustrating sizes of rock near the tunnel approach

It is observed from the table that maximum weight of the detached rock is 1300 kg

Comparison between Concrete Shed tunnel and Flexible Steel shed tunnel

	Open Cut Tunnel	**Flexible Steel Shed Structure**
Construction technology	Needformworks,pouringandbackfilling	Simple Process
Construction Organization System	Complicated organization system, requires more number of workers	Simple Organization System and Position composition
Construction Auxiliary Equipment	Needs Excavators Loaders Agitators etc.	Large machinery is Wheeled truck crane
Construction Period	Long	Easy installation

Table :2 Benefits of FST over conventional method

Loading Calculation:

The loading on portal is as follows

A. **Dead Load –**Self weight of the structural members have been taken in to a/c with self-weight command and factor of -1.1 in staad pro software.

Dead load of the mesh has been taken as **0.5 kN/$m^{2.}$**

B. **Live Load –** The live load is due to dynamic load of rock fall which is generated and applied as time history graph & explained in analysis section.

C. **Wind Load –** The wind loads are calculated as per IS 875 Part III

Where, Basic wind speed (Vb) =**62 meter/sec (Manipur)**
Design Wind Speed (Vz) = Vb*K_1*K_2*K_3*K_4
=**53.5 meter / sec.**

Design wind pressure (Pz) = .6 Vz^2
= **1717.3 N/m^2= 1.71kN/m^2,** where,

Risk Co efficient factor (K_1) = 1.08 (IS 875, part III, Section 5.3.1, Table -1)
Terrain and Height factor (K_2) = .8 (IS 875, part III, Section 5.3.2.2, Table -2)

Topography factor (K_3) = 1 (IS 875, part III, Section 5.3.1.1)
Importance factor for cyclonic reason (K_4) = 1 (IS 875, part III, Section 5.3.4)
The solidity ratio considered .25 (IS 875, part III,)

Wind load on member = 1.71 * .25 * 3 * 1.8
= 2.29**kN/m**, where, Bay spacing is 3 m.

D. **Earthquake Load –**

The design horizontal seismic coefficient Ah= $\frac{Z*I*Sa}{2*R*G}$, Where,
Zone factor (Z) = 0.36 (IS 1893, part I, Section 6.4.2, table-2)
Importance factor (I) = 1.5 (IS 1893, part I, Section 6.4.2, table-6)
Response reduction factor (R) = 5 (IS 1893, part I, Section 6.4.2, table-7)
Rest of the factors of seismic taken care in staad like joint weight etc.

Design Method: –

The analysis and design has been carried out in the following steps-

A. Analysis by Rocfall software to determine the velocity, weight, and diameter of the rock fall on the flexible shed structure.
B. The deflection and stresses on the mesh has been determined by modelling and analyzing the mesh by Finite element method in staad. The deflection so obtained will be added to the clearance height required by the railway to determine the final height of the structure frame @3m c/c
C. Based on data obtained from the rocfall software and finite element analysis of the mesh the requires data have been input in the space frame model in staad pro through which analysis and design has been come out. Considering two boulders impacting on the main frame at the same time at different positions as listed below.

Analysis:

We have analyzed the profile of the hill by placing the boulder at different height and of different mass, size. Software gave us the respective energy, velocity, and the point of fall on the ground found out. We do these iteration

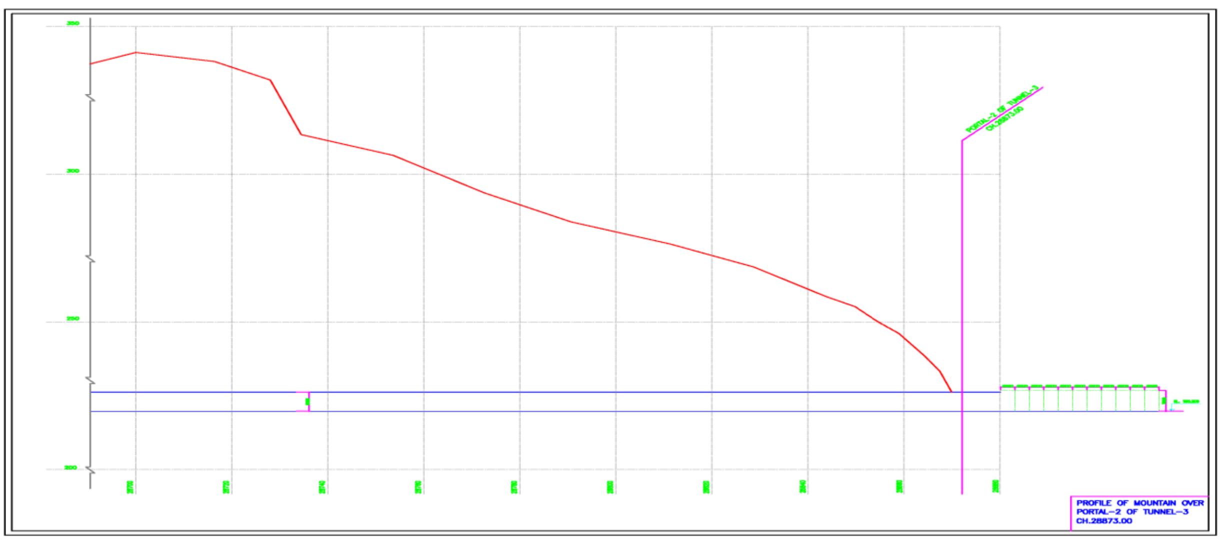

Figure3: Profile of hill over tunnel

until we got the desired energy i.e. 500KJ

We required the properties related to the boulder of 500 KJ but we took the properties of the boulder which generates the 560 KJ in order to provide the some factor of safety to the structure.

The properties and the results of different boulders which was analyzed in the software are shown below.

Table: Analysis Result

Sl.No.	Description	Boulder Diameter (m)	Density (kg/m^3)	Boulder Mass (kg)	Required length of Shed (m)	Source point of Rockfall (m)	Maximum Energy generated at barrier(KJ)	Maximum Velocity (m/sec)
1	T-3 P-2	0.5	2700	176.7	6.4	51.8	56.9	23.6
2	T-3 P-2	0.7	2700	484.9	6.5	59.55	165.572	24.072
3	T-3 P-2	0.76	2700	620.6	9.4	75	235.21	24.171
4	T-3 P-2	0.8	2700	723.8	6.5	82.5	291.9	26.147
5	T-3 P-2	0.88	2700	963.4	6.5	90.8	389.043	26
6	T-3 P-2	0.96	2700	1250.8	6.4	97.7	477.322	24.9
7	T-3 P-2	0.980	2700	1330.6	6.5	118	502.8	25
8	T-3 P-2	1.02	2700	1500.2	6.5	123	560	24.8

Table :3 Result Analysis

For further calculations we took the properties of the serial no 8 boulder from above table which generates 560 KJ and the screenshot related to this analysis are shown under

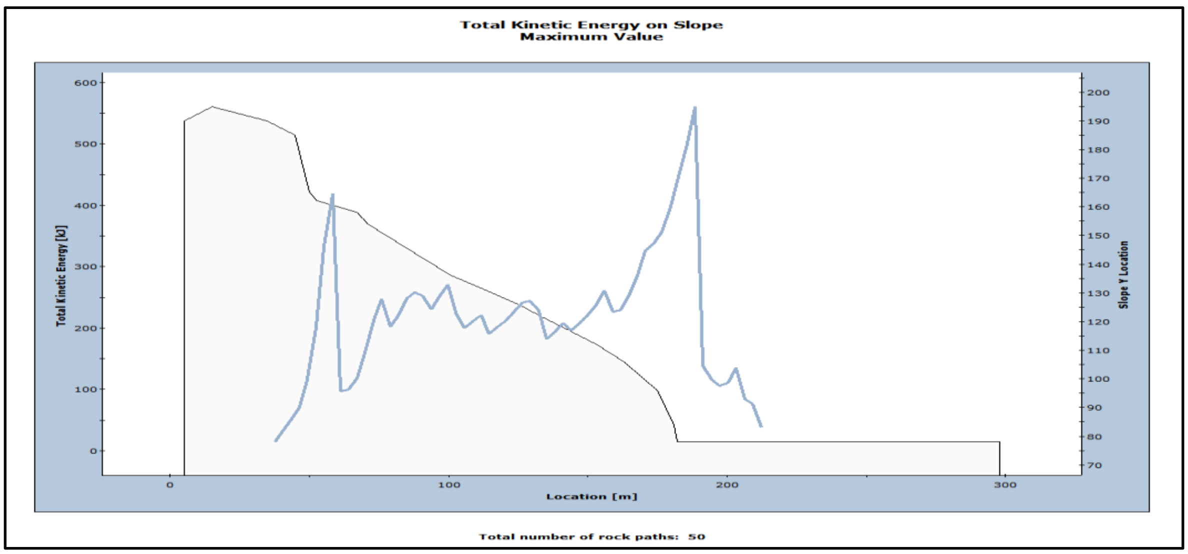

Figure 4: The achieved Total Kinetic Energy is 560 KJ.

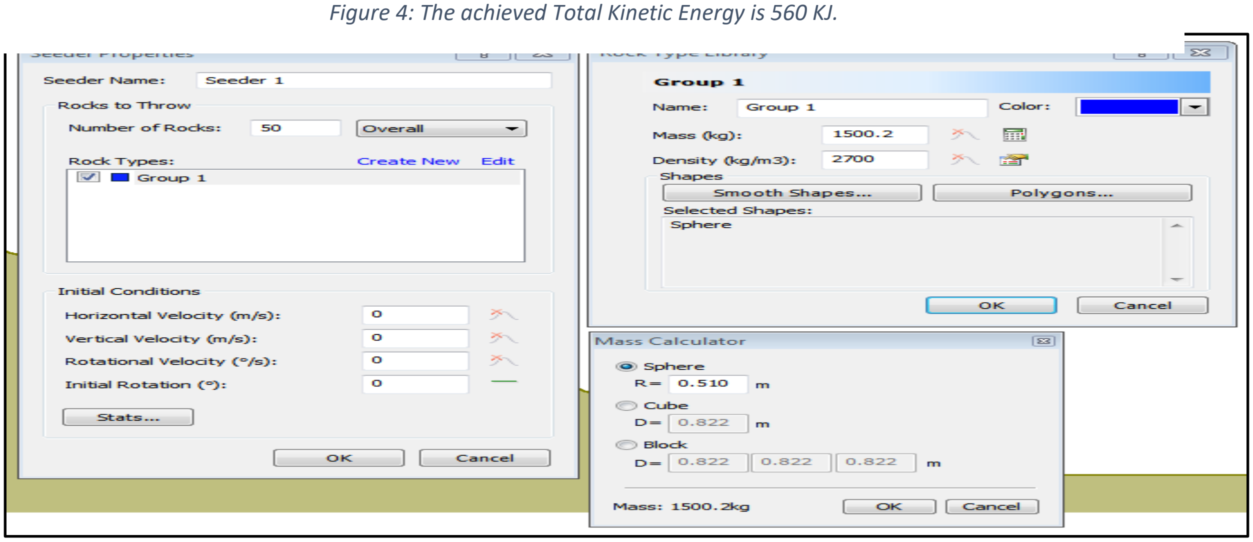

Figure 3: Total Kinetic Energy

<u>Tunnel</u>–Maximum distance of rock fall on ground is 10 meter.

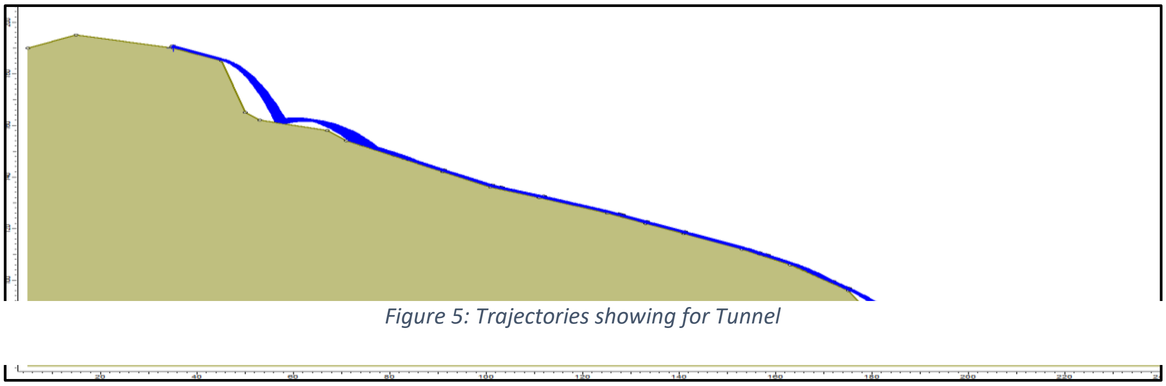

Figure 5: Trajectories showing for Tunnel

Graphical Representation:

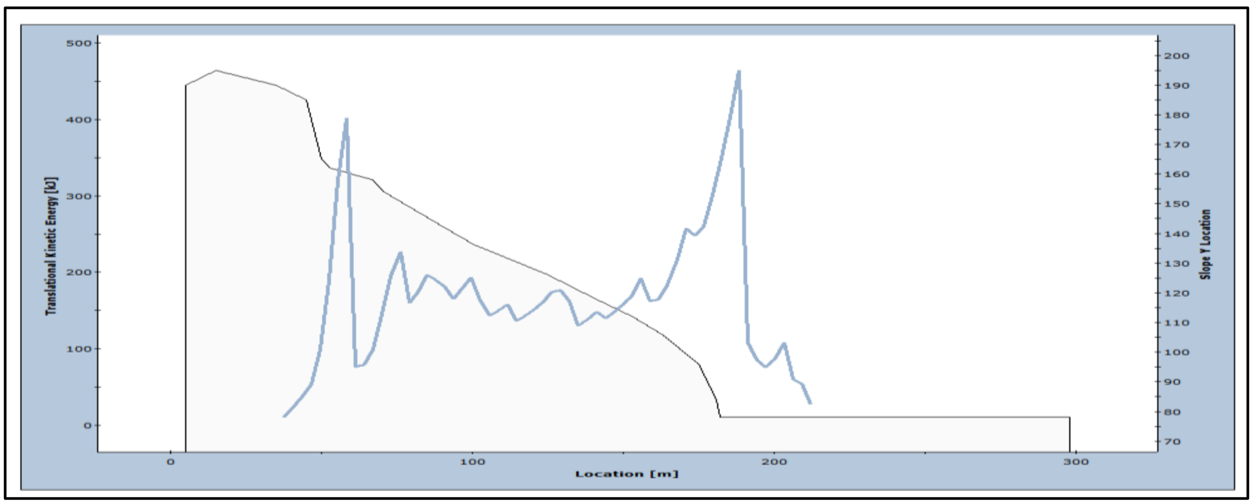

Figure 6: Rotational Velocity

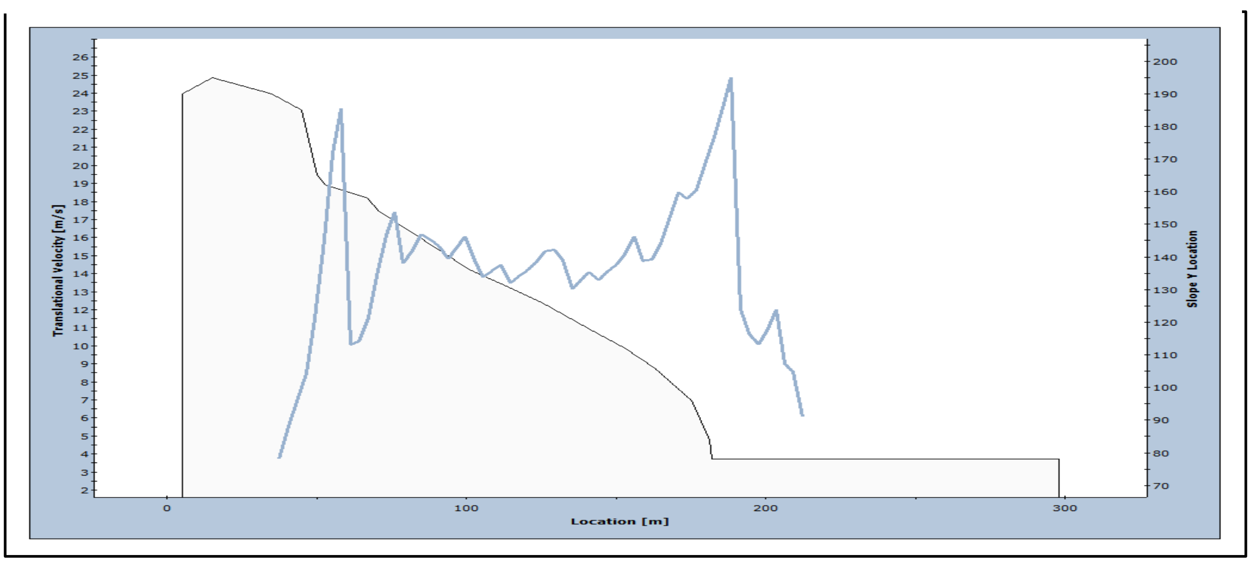

Figure 7: Translational Velocity

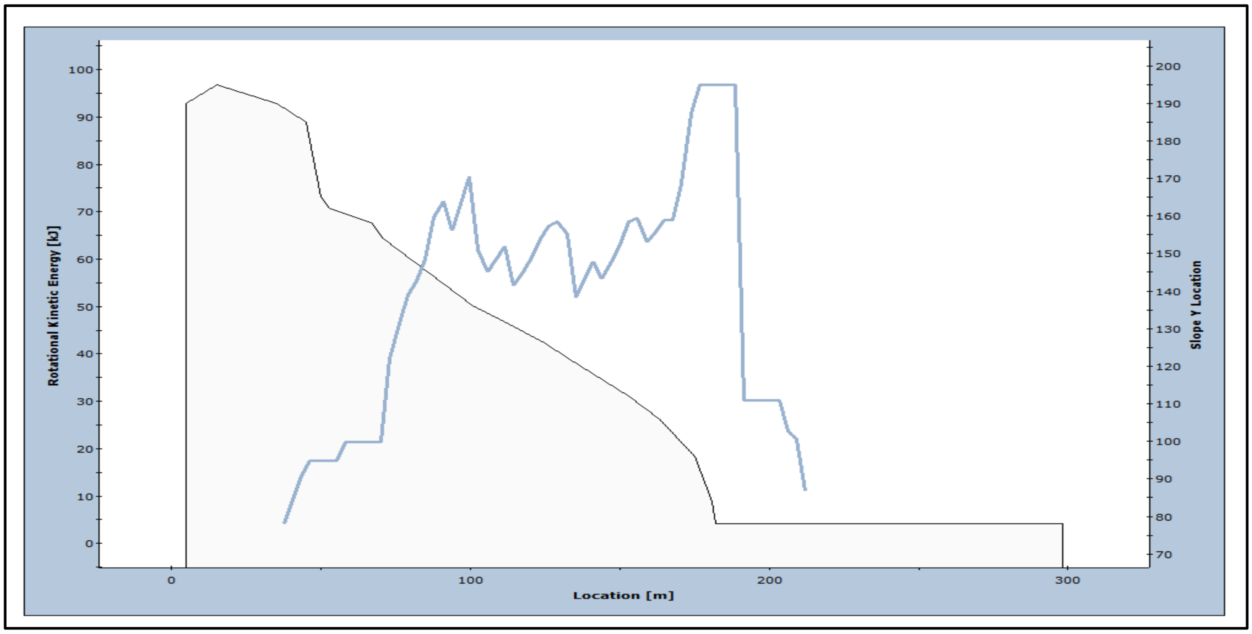

Figure 8: Translational Kinetic Energy

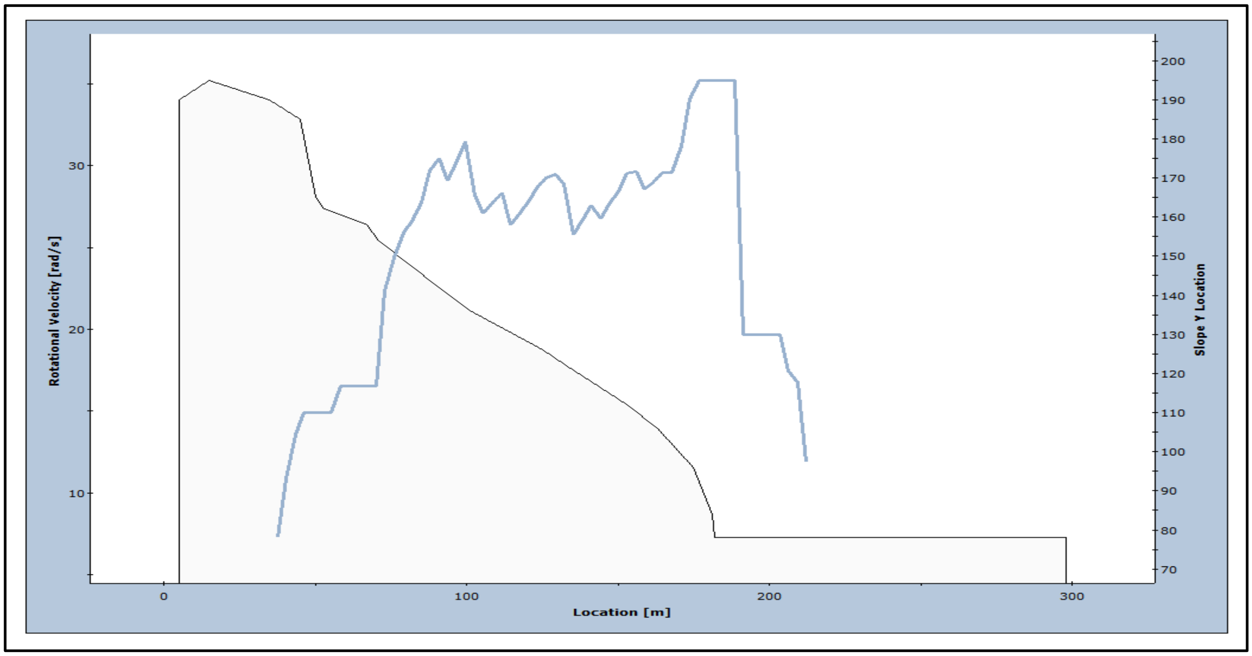

Figure 9: Rotational Kinematic Energy

Finite Element Analysis of Mesh:

Here in the analysis we place the longitudinal supporting rope at a distance of 1.5 m.

Size of ring net =300mm

Ring net consist of 9 wires of 3 mm diameter.

Modulus of elasticity (E) for ring net and supporting ropes =1.77e+008kN/m^2

Poisson's Ratio =0.3

Density=78.5 kN/m^3

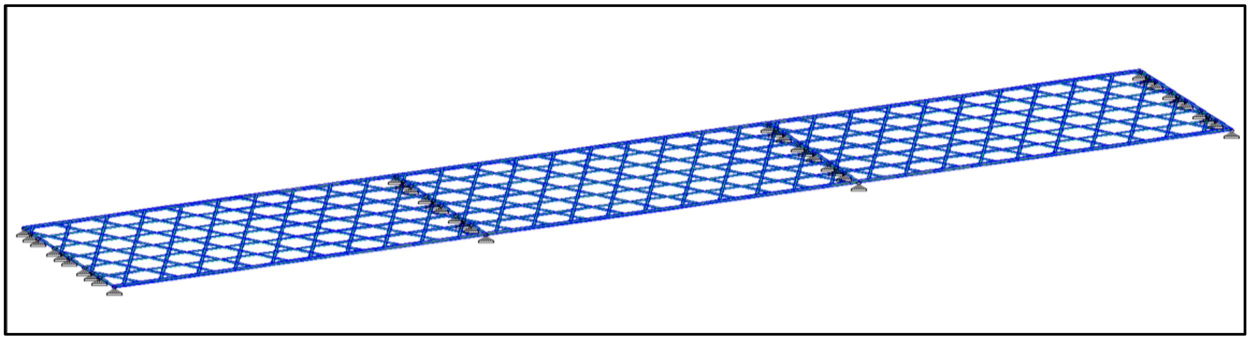

Figure 11: General view of the Model

Result:

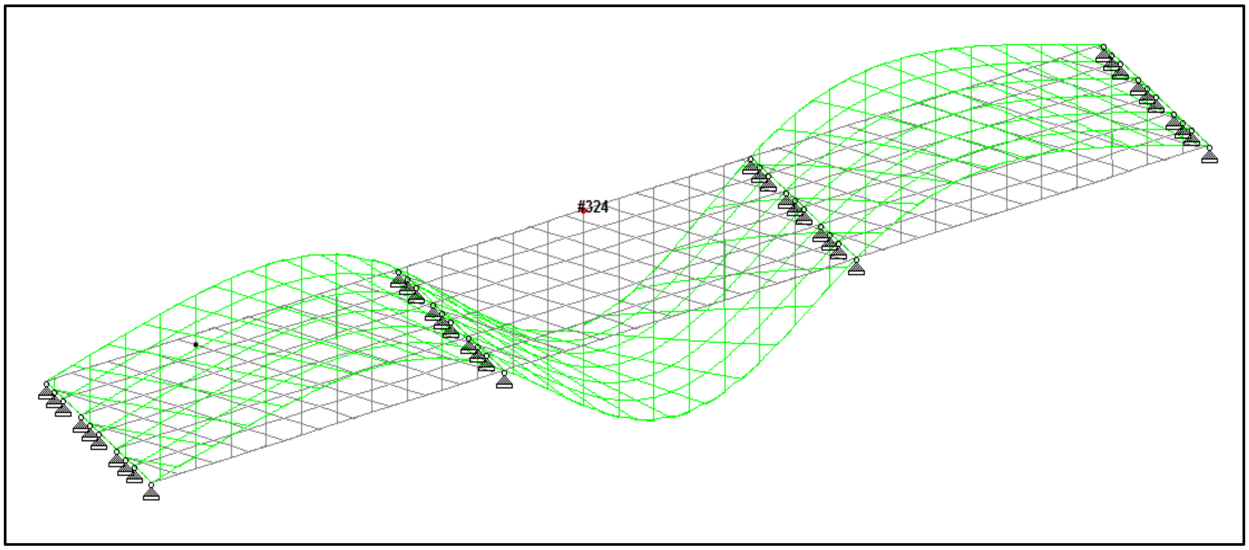

Figure12: Showing the node of maximum displacement

DESCRIPTION	L/C	NODE	Y-Trans mm	Z-Trans mm	Absolute mm	X-Rotan rad	Y-Rotan rad	Z-Rotan rad
MAX. JOINT DIPLACEMENT	DL+IMPACT	324	-886.03	0	886.032	-0.346	0	0.17

DESCRIPTION	L/C	Beam	Axial N/mm2	Bend-Y N/mm2	Bend-Z N/mm2	Combined N/mm2	Shear-Y N/mm2	Shear-Z N/mm2
MAX MESH STRESS	DL+IMPACT	581	0	0	2547.183	2547.183	-2.345	0

DESCRIPTION	L/C	Beam	Axial Force kN	Shear-Y kN	Shear-Z kN	Torsion kNm	Moment-Y kNm	Moment-Z kNm
MAX MESH FORCES	DL+IMPACT	429	0	7.598	0	0	0	1.229

Diameter of supporting rope comes out =21mm

STRUCTURAL FRAME ANALYSIS AND RESULTS

The structure has been modeled and analyzed in the staad by the inputs obtained from the Rocfall software and by considering the loading discussed in the loading section. The results and members sections comes out are discussed below.

The height of the structure decided to be the railway clearance height plus the deflection of mesh =5.87+.886=6.756m, approx. 6.8 m.

From the software analysis it derived that, maximum time of contact and energy generated on main steel member are 0.27s and 270 KN respectively.

The maximum time of contact and energy generated on mesh member are 0.4s and 78.4 KN respectively.Deflection obtained due to the impact on mesh is 886mm.

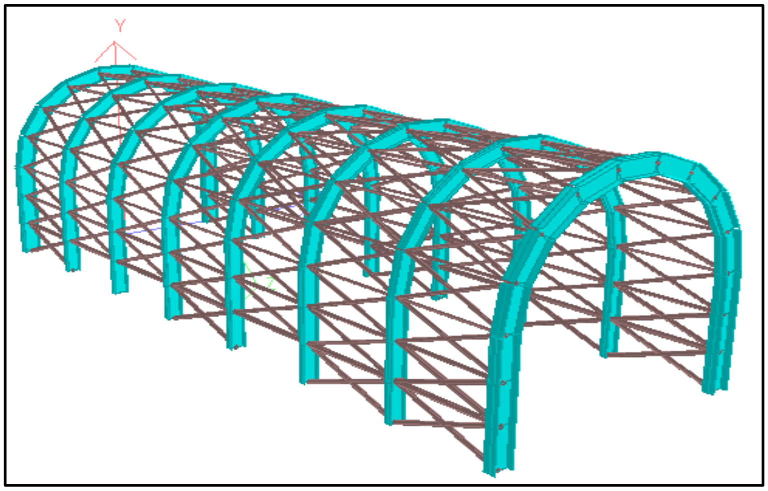

Figure 10: Rendered view of the structure

Conclusion:

Post analysis of trajectory movement of boulders near the tunnel crown,its observed that with the installation of FST, incidence of shooting of boulders can be reduced and can be guided to slide down safely. From the energy absorption analysis the impact energy is within the permeablerange of the design. In addition to that, tunnel near the approach will receive extra illumination and will result in the uninterrupted railway movement. The length of the flexible tunnel is calculated as per the analysis of trajectory path from the simulation.

Thus from the above analysis it is deduced that the fragmented rocks which was disintegrating from the high mountains, rolling down, falling on the railway track can be prevented, guided in a controlled manner to fall away from the track and livelihood.

Also the design is carried out considering the mass of the highest mass, dimension of the boulders falling near the track. Post analysis of the impact energy, yield load is considered, design load is calculated accordingly. Steel wiremesh is designed and the supporting steel frames which can withstand the impact of the rolling stones from that greater height.

Thus from the above analysis, calculation and simulation, an effective FST is designed and installed at site for railways which is functioning as per designed.

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