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Structural Performance Evaluation of Multi Storey Building Considering Different Sloping Angles with Bracing Systems Using Tekla Structural Designer

Mahesh S Mudigowdar¹, Savan R G Basavaraj²

¹Student, M Tech. in Structural Engineering, Department of Civil Engineering, Bapuji Institute of Engineering and Technology, Davangere-577004, Karnataka

²Assistant Professor, Department of Civil Engineering, Bapuji Institute of Engineering and Technology, Davangere-577004, Karnataka

Abstract: This study investigates the seismic behavior of a structure on sloping ground with inclinations of 0°, 5°, and 10°, analyzed in TEKLA Structural Designer using the Response Spectrum Method for Seismic Zone II. Results from graphs and tables highlight variations in structural performance under different slopes. Case 2 (5° slope) exhibits the highest effective seismic weight of 91,019 kN, resulting in maximum base shear forces of 2,204.60 kN (code-based) and 1,750.70 kN (modal analysis). Its higher mass and stiffness make it the most seismically demanding and dynamically stable structure, showing the shortest natural period, highest frequency, and significant mass participation in the initial modes. Case 2 also demonstrates the highest storey shear in the Y-direction (2,961.86 kN), storey sway in both X (260.53 mm) and Y (269.19 mm) directions, and seismic drift of 4 mm in the Y-direction. Case 1, on flat ground, records maximum shear in the X-direction (2,534.52 kN) and maximum drift of 3 mm in X. The maximum storey force in the X-direction occurs in case 3 (503.67 kN). Case 2 also demands the most reinforcement (213,156.33 kg), confirming that sloped ground increases stiffness, mass, and overall seismic demand.

Keywords: TEKLA Structural designer, Seismic loads, Bracings.

I. INTRODUCTION

Rapid urbanization and limited flat land in hilly regions have led to an increase in multistorey building construction on sloping terrain. Unlike flat-ground structures, slope-based buildings develop geometric, mass, and stiffness irregularities that make them more susceptible to seismic forces. Past earthquakes have revealed that such buildings often suffer severe damage due to torsional effects, uneven foundation levels, and irregular load distribution. The slope angle further influences a structure's dynamic properties, including natural frequency, mode shapes, and base shear behavior, significantly affecting its seismic response.

To address these challenges, engineers are increasingly using advanced tools like Tekla Structural Designer (TSD), which enables precise modeling, load application, and dynamic analysis while complying with Indian and international design codes. This study presents a comparative seismic analysis of a G+6 RCC building constructed on slopes of 0°, 5°, and 10° using TSD. The objective is to evaluate how slope variations impact key seismic parameters such as base shear, storey drift, lateral displacement, and mode shapes. By examining these factors, the study aims to enhance understanding of slope-induced seismic behavior and contribute to developing safer, more efficient design practices for earthquake-prone hilly areas where construction on sloping terrain with bracings.

II. TEKLA STRUCTURAL DESIGNER

Tekla Structural Designer is advanced structural analysis and design software developed by trimble. Created for structural engineers to design and analyse building, combining both analysis and design into a single seamless process. Traditional tools require separate modelling, analysis and design platform, TSD allows enineers to create a single 3D model that integrate all aspects of the structure.

TSD helps structural engineers by:

- 1) Reducing time by automated load calculations and code checks
- 2) Allowing quick evaluation of different design alternatives
- 3) Providing 3D visualisation of structural behaviour
- 4) Generating detailed design reports, drawings and reinforcement schedules

Ensuring safety and serviceability through codal compliance

III. BUILDING DESCRIPTION

Table 1 Shows the design parameters adopted for the developed RCC model

Table 1: Design parameters adopted for the developed RCC model

Sl. No	Particulars	Dimensions
1	Design code	IS Codes
2	No. of floors	G+5+Terrace
3	Site location	Mid Karnataka
4	Seismic zone	II
5	Type of building	RCC
6	Total height of building (m)	23.90
7	Floor to floor height (m)	3.2
8	Base to ground height (m)	1.5
9	Grade of concrete	M30
10	Grade of steel	Fe550
11	Size of column (mm)	600X600, 300X600
12	Bracings size (mm)	150X150X15
13	Beam size (mm)	300X450
14	Slab thickness (mm)	180 mm
15	Concrete density (kN/m ³)	25
16	Solid brick density (kN/m ³)	20
17	Mortar density (kN/m ³)	20.4
18	Earthquake Load	As per IS:1893-2016

Table 2 Shows the structural elements of our project

Table 2: Structural elements of our project

BUILDING TYPE	CASE NO.
RCC structure with 0-degree slope with bracings	Case 1
RCC structure with 5-degree slope with bracings	Case 2
RCC structure with 5-degree slope with bracings	Case 3

Figures from 1to 3 shows the 3D view of the developed models.

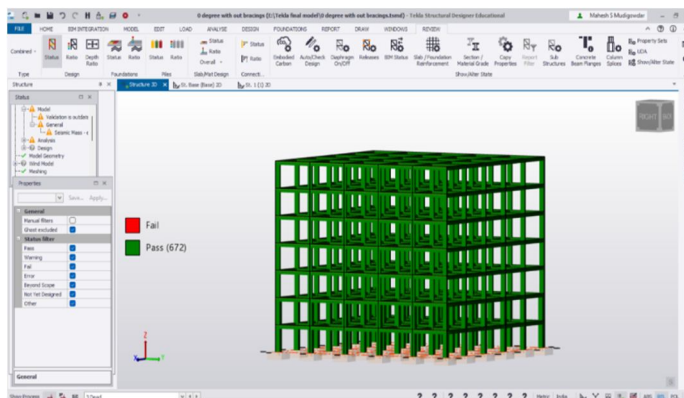


Fig. 1: 3D View of 0° structure in TEKLA

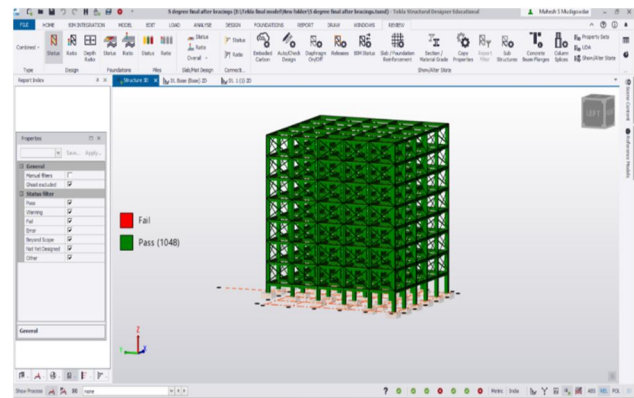


Fig. 2: 3D View of 5° structure in TEKLA

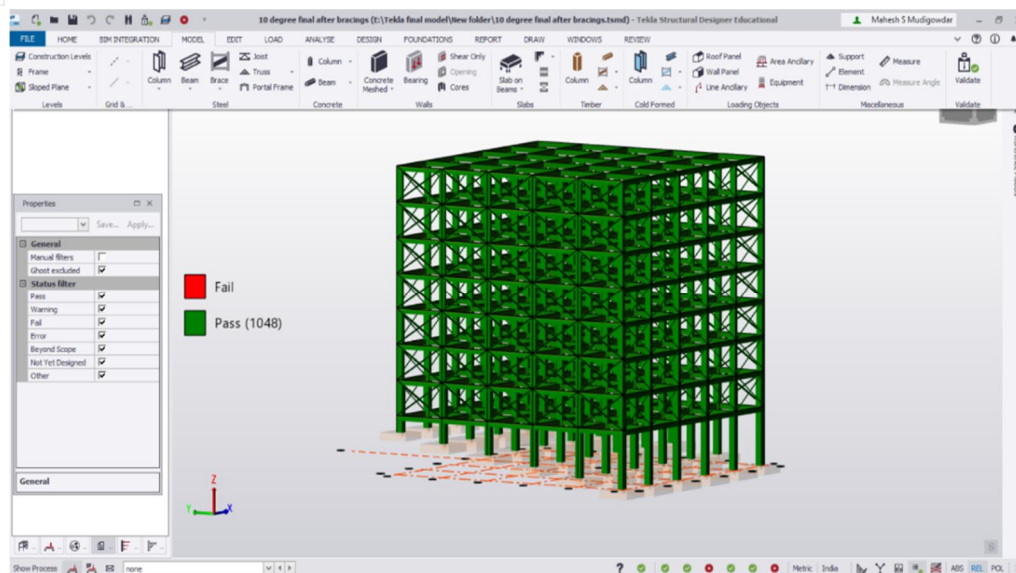


Fig. 3: 3D View of 10^o structure in TEKLA

A. Load Considerations For Structure

The loads considered for modelling and analysis remain the same for all the different types of bracings mentioned above, and the corresponding manual calculations are as follows.

1) Static Load Application

Table 3: Static Load Details

Main wall load (kN/m)	15 (IS:875 part 1)
Partition wall load (kN/m)	6 (IS:875 part 1)
Floor finish (kN/m ²)	1 (IS:875 part 1)
Live load (kN/m ²)	5 (IS:875 part 1)

2) Earthquake Load Application (Seismic Load)

In Tekla Structural Designer, the seismic load application can be directly selected from the available load cases as per the relevant design codes.

Table 4: Seismic Load Details

Seismic Summary	
Location	Mid Karnataka
Zone actor	Z=0.10
Code	IS 1893: 2016 Part 1
Response Reduction Factor(R)	3
Importance Factor (I)	1.2
Damping Ratio (%)	5
Soil Category	Type II Medium Soil

3) Load Combination

Table 5: Load Combination Details

SL. NO.	LOAD COMBINATION
1	Effective Seismic Weight
2	(Final) $LS_2-1.5D+1.5L+1.5L_r$
3	(Final) $LS_{4,1}-1.2D+1.2L+1.2L_r\pm1.2E$
4	(Final) $LS_{4,2}-1.2D+1.2L+1.2L_r\pm1.2E$
5	(Final) $LS_{6,1}-1.5DB1\pm1.5E$
6	(Final) $LS_{6,2}-1.5DB1\pm1.5E$
7	(Final) $LS_{8,1}-0.9DB1\pm1.5E$
8	(Final) $LS_{8,2}-0.9DB1\pm1.5E$

IV. ANALYSIS OF RCC MODEL

- 1) A model with no slope is first developed in Tekla Structural Designer and analyzed for its behavior using the Response Spectrum Method of Analysis.
- 2) Different loads such as dead loads, live loads, and seismic loads are considered for the analysis of both sloped and non-sloped RCC structures within Tekla Structural Designer.
- 3) Subsequently, additional RCC structures with varying slope angles (5° and 10°) are modeled to study their behavior under the Response Spectrum Method of Analysis.
- 4) The performance of different structural systems is then evaluated based on the output results obtained from Tekla Structural Designer.
- 5) A comparison is made between various parameters such as storey drift, displacement, and shear force for the different buildings to draw insights about the structures analyzed through the Response Spectrum Method of Analysis.
- 6) Based on the results, conclusions are drawn on how the result parameters vary for with and without sloped grounds in terms of seismic performance.

V. RESULTS AND DISCUSSION

Figures 4 to 8 shows the variation of seismic loading summary, modal response spectrum analysis is permitted, modal frequencies, storey forces, storey shear, storey sway, seismic drift, material listing over the number of stories in both X and Y directions obtained for all the RCC models by Equivalent static method.

Comparative evaluation of different slope cases

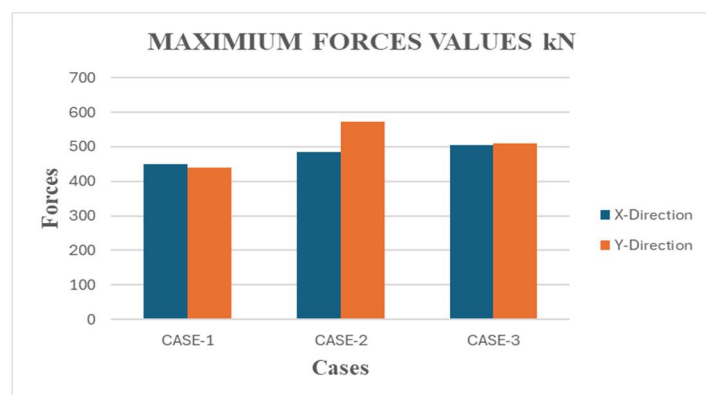


Fig. 4: Max. Storey Forces for all Case

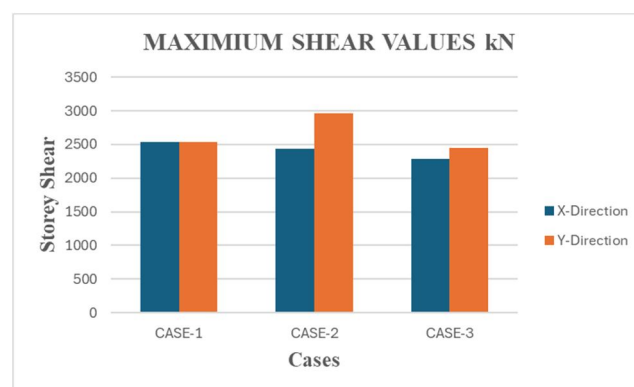


Fig. 5: Max. Storey Shear for all Case

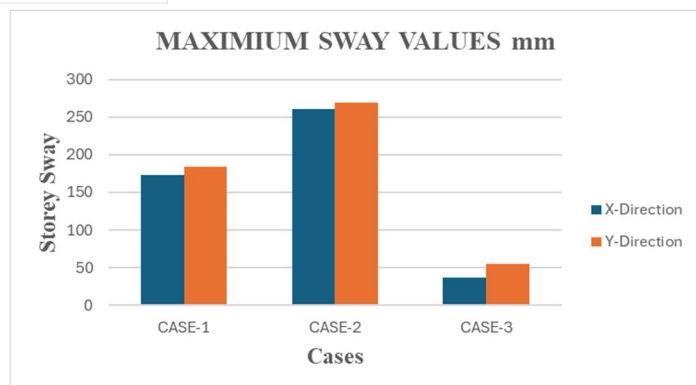


Fig. 6 Max. Storey Sway for all Case

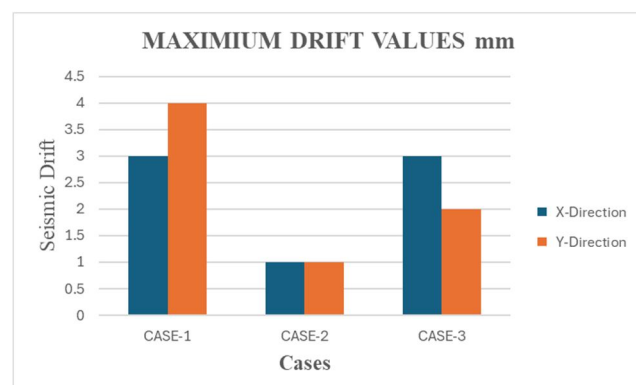


Fig. 7: Max. Seismic Drift for all Case

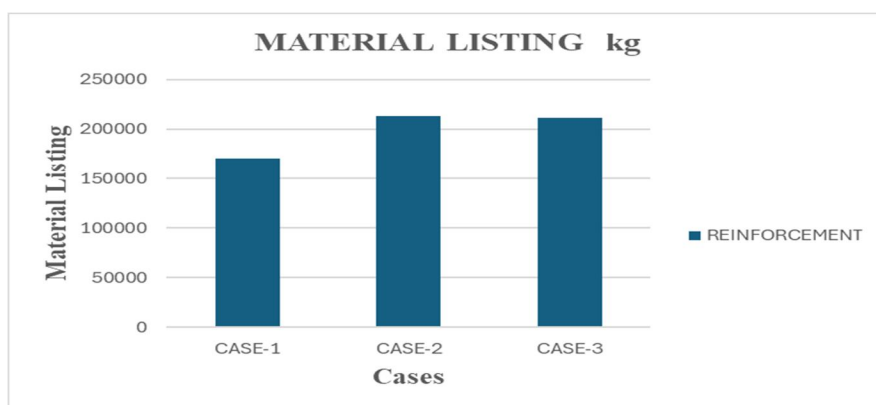


Fig. 8: Max. Material List for all Case

- 1) The maximum storey force values in both x and y directions for all three cases are summarized below. Among them, Case-3 shows the lowest storey forces, with values of 26.55kN in the x direction and 24.74kN in the y direction. Compared to the other cases, this indicates that Case-3 experiences the least seismic force demand.
- 2) The maximum storey shear values in both x and y directions for all three cases are summarized below. Among them, Case-1 shows the lowest storey forces, with values of 449.34kN in the x direction and 440.32kN in the y direction. Compared to the other cases, this indicates that Case-1 experiences the least seismic shear demand.
- 3) The maximum storey sway values in both x and y directions for all three cases are summarized below. Among them, Case-1 shows the lowest storey forces, with values of 11.710mm in the x direction and 11.231mm in the y direction. Compared to the other cases, this indicates that Case-1 experiences the least storey sway demand.
- 4) The maximum storey sway values in both x and y directions for all three cases are summarized below. Among them, Case-2 shows the lowest storey forces, with values of 0mm in the x direction and 0mm in the y direction. Compared to the other cases, this indicates that Case-1 experiences the least seismic drift demand.
- 5) The maximum material listing values for all three cases are summarized below. Among them, Case-1 shows the lowest material listing, with 169972.15kg. Compared to the other cases, this indicates that Case-1 experiences the least material listing demand.

VI. CONCLUSION

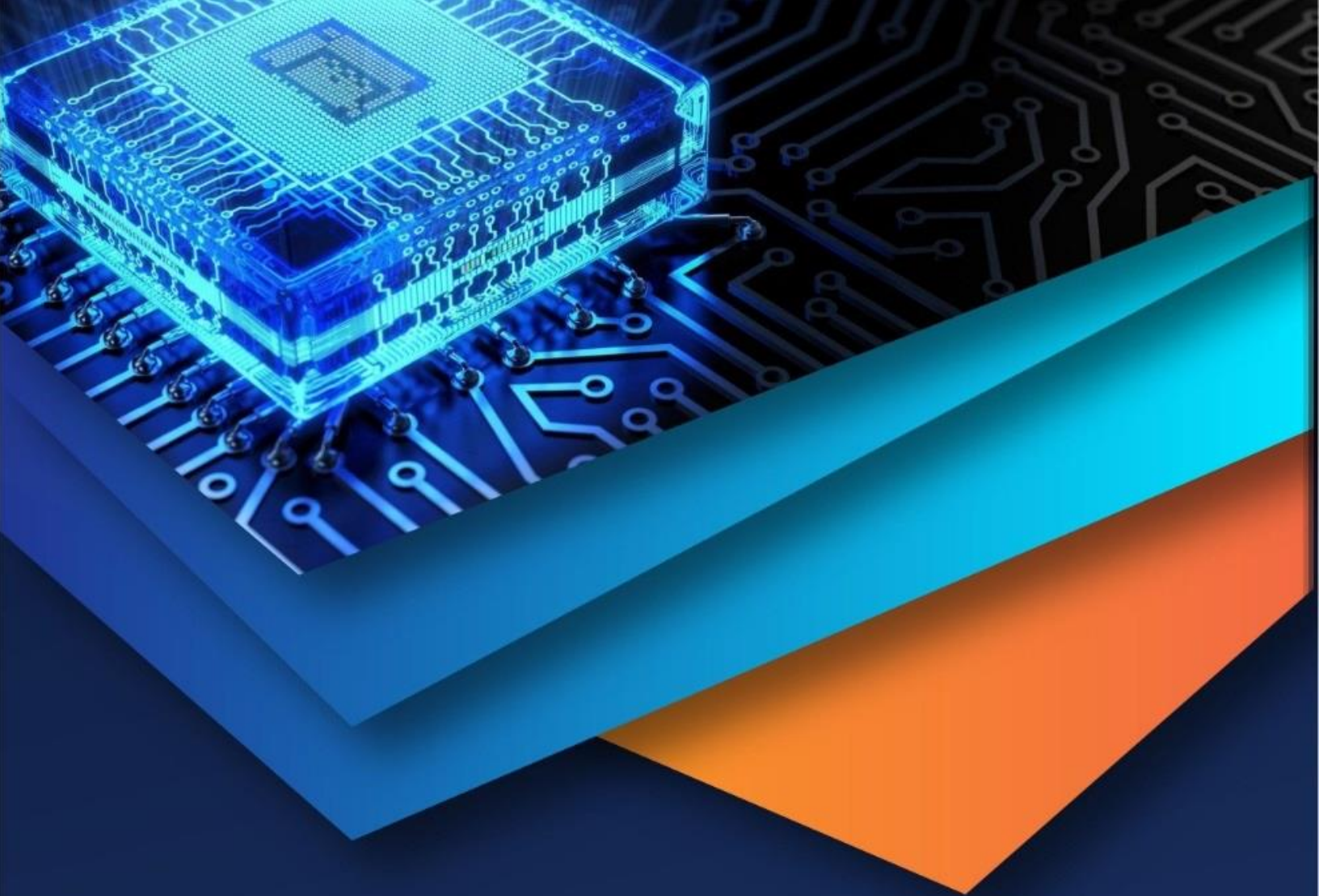
In this study, we examined how the structure behaves on different sloping ground conditions by considering slopes of 0°, 5° and 10°. The analysis was carried out in TEKLA STRUCTURAL DESIGNER using the Response Spectrum Method of Analysis (RSMA) for seismic Zone II. The results have been compared through graphs and tables, which provided a clear understanding of the structure on varying slopes. Based on these observations, the following conclusions were drawn.

- 1) In Case 2, the structure carries the highest effective seismic weight of 91,019.00kN, which results in the largest base shear forces 2,204.60kN from code-based calculations and 1,750.70kN from modal analysis. This indicates that Case 2 more stiffest among the three model.

- 2) The modal response spectrum analysis of Case 2 shows the maximum values, with higher modal base shear at the top levels and a more uniform distribution of shear across the structure.
- 3) The maximum values for modal frequencies Case 2 have the shortest natural period and the highest frequency, indicating a dynamically stable and well-balanced structure with efficient seismic performance.
- 4) The maximum values for storey force in X-direction are maximum for Case 3 of 503.67kN and maximum storey force in the Y-direction is maximum for Case 2 of 572.86kN on sloped ground with bracings.
- 5) The maximum values for storey shear in X-direction are maximum for Case 1 of 2534.52kN and maximum shear force in the Y-direction is maximum for Case 2 of 2961.86kN on sloped ground with bracings.
- 6) The maximum values for storey sway in X-direction are maximum for Case 2 of 260.53 mm and maximum storey sway in the Y-direction is maximum for Case 2 of 269.19mm on sloped ground with bracings.
- 7) The maximum values for seismic drift in X-direction are maximum for Case 1 of 3 mm and maximum seismic drift in the Y-direction is maximum for Case 2 of 4 mm on flat ground with bracings.
- 8) The maximum material listing values in Case 2 is 213156.33kg indicates higher reinforcement demand on sloping ground with bracings.

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