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Response of Segmental Bridge when Subjected to Seismic Excitation

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Abstract - *Segmental box girder bridges externally post-tensioned are one of the major new developments in bridge engineering in the last years. In contrast to 'classical' monolithic constructions a segmental bridge consists of „small" precast elements stressed together by external tendons The segmental method is an accepted and economic construction technique; however, the related design task is extremely demanding and technically ambitious. Generally it requires sophisticated structural analyses, where all properties influencing the deformation behavior are properly taken into account. These requirements include inter alia the consideration of structural non-linearity, creep and shrinkage behavior, pre-camber and deformation control during erection.*

The designed segmental bridge was of 8.8m width, a depth of 2m and a length of 31m with M50 grade concrete. The structure is subjected to different seismic forces in different zones of India and the results were tabulated for comparison.

Key Words: Segmental Bridge, Base Shear, Moment, Stress, Displacement

1. INTRODUCTION

From past few decades the infrastructure has seen a great boom in the world. To access any inaccessible areas bridges were built. Hence building bridges became mandatory for infrastructure development. During the ancient time natural bridges were created by nature as in tree trunks extended to the inaccessible areas. Then humans started building their artificial bridges to travel to other side of the valley or non transportable point. The bridges built by humans were usually made of wood or bamboo thatch. As the population increased the need for bigger and sturdier bridge was more. This led for innovation in bridge building techniques thus many types of bridges were formed.

Segmental box girder bridges externally post-tensioned are one of the major new developments in bridge engineering in the last years. In contrast to 'classical' monolithic constructions a segmental bridge consists of „small" precast elements stressed together by external tendons The segmental method is an accepted and economic construction technique; however, the related design task is extremely demanding and technically ambitious. Generally it requires sophisticated structural analyses, where all properties influencing the deformation behaviour are properly taken into account. These requirements include inter alia the consideration of structural non-linearity, creep and shrinkage behaviour, pre-camber and deformation control during erection.

1.1 Seismic loads

Seismic loads create a large impact on the structure. Ground motions are typically measured and quantified in three primary directional components. Two of these components are orthogonal and in the horizontal plane, while the third component is in the vertical direction. The vertical component of ground motion is known to attenuate faster than its horizontal counterparts. Therefore, the impact of vertical ground motion on a bridge structure is typically minimal for bridges located at distances approaching 100 km from active fault. For structures in moderate-to-high seismic regions and close proximity to active faults (<25 km), the vertical component of ground motion is much more prominent, and may be damaging in parallel with horizontal components.

1.2 Vehicle loads

For live load purposes vehicular load is taken as the live load on the bridge. The load of vehicles is taken according to the IRC 6. There are 3 types of standards types

- IRC class AA
- IRC class A
- IRC class B

Class AA – This type of class is a tacked vehicle with 70 tone weight or a wheeled vehicle with 40 tone weight as shown in the figure.
Class A – wheel load train composed of a driving vehicle and two trailers of specified axle spacing's.
Class B is loading of temporary structure and for bridge in some special cases.

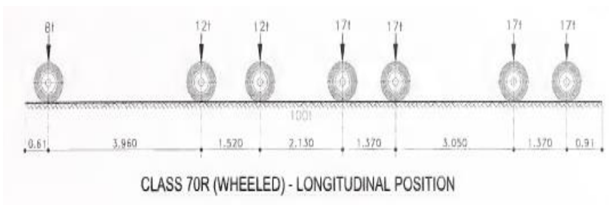


Figure 1 - Class 70 R wheel load

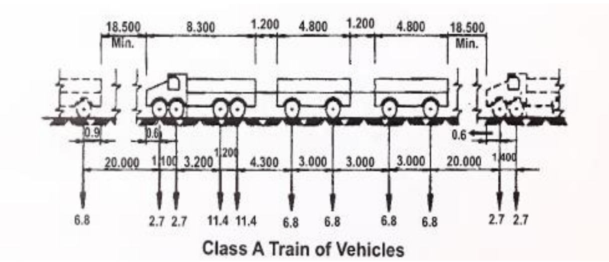


Figure 2 - Class A wheel load

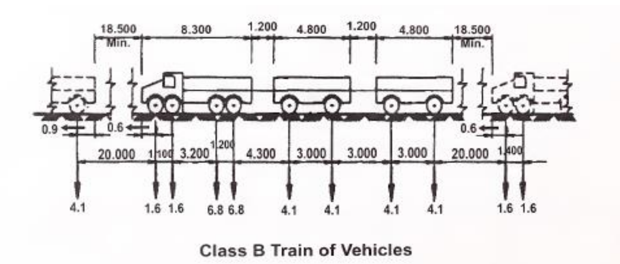


Figure 3 - Class B wheel load

2. Project Objective

To study the behavior of segmental bridge when it subjected to different seismic forces in different zone of India with different soil conditions. IS 1893(Part 1) 2002, FBD, DBD were calculated and graphically compared with each other. The structure is also subjected to occurred earthquakes and Shear moment and stress were calculated.

3. METHODOLOGY

3.1 General

This chapter emphasizes on the method used to study the behavior of curved bridges. The details of software used and the steps followed for analysis is dealt in this chapter.

3.2 Methodology adopted

- The selected bridge was designed for Zone II of India.
- The model was designed using software and loads including self weight and live load were applied to know the reaction at the bottom of the pier.
- Different methods like as per IS 1893 (part 1) 2002, FBD and DBD and response for occurred earthquakes was calculated.
- The above procedure is repeated for each Zones of India with different soil conditions.

3.3 Description of model

The software used for modeling is STAAD.Pro

- For the whole structure grade of the concrete used was M50.
- The column was designed with Fe 500 steel with a dimension of 1.6m*2.8m. Height of the column from ground level is 16m.
- A segmental deck was designed for a width of 8.8m and of depth 2m. The overall length was 31m. In which it was divided into 11 parts, in which two segments of 2m of each at beginning and end of the deck and remaining nine segments of 3m each.

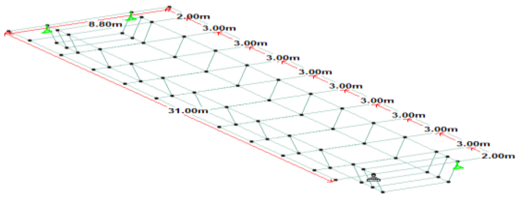


Figure 4 –3 D view of Segmental

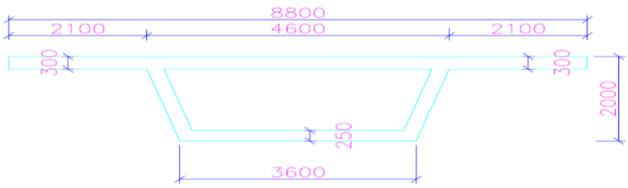
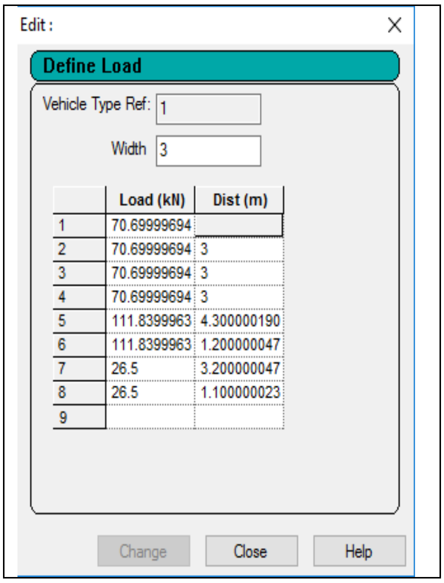


Figure 5 –Segmental Bridge Cross Section

3.4 Loading pattern

1. Vehicle load – Load is applied according to IRC A, IRC AA and IRC 70 R wheel load.
2. Seismic load – The load was varying with different zones and different type of soil conditions.

Table -1: Vehicle load Pattern in STAAD.Pro



	Load (kN)	Dist (m)
1	70.69999694	
2	70.69999694	3
3	70.69999694	3
4	70.69999694	3
5	111.8399963	4.300000190
6	111.8399963	1.200000047
7	26.5	3.200000047
8	26.5	1.100000023
9		

4. RESULTS AND DISCUSSION

The models were analyzed separately and results were noted. The results were compared.

4.1 As Per IS 1893(Part 1) 2002:

For Rock soil, time period is more than 0.40 sec, so $Sa/g = 1/T_n$

Table -2: Code analysis for Rock

Zone	II	III	IV	V
Sa/g	1.67	1.67	1.67	1.67
Response Factor R	5	5	5	5
Importance Factor **I**	1.5	1.5	1.5	1.5
Zone Factor **Z**	0.1	0.16	0.24	0.36
Horizontal Seismic Coefficient **Ah**	0.025	0.040	0.06	0.09
Base Shear **Vb in kN**	1758	2813	4219	6329
Moment **M in kN-m**	28130	45007	67511	101267

For Gravelly soil, time period is more than 0.55 sec, so $Sa/g = 1.36/T_n$

Table -3: Code analysis for Gravel

Zone	II	III	IV	V
Sa/g	2.27	2.27	2.27	2.27
Response Reduction Factor **R**	5	5	5	5
Importance Factor **I**	1.5	1.5	1.5	1.5
Zone Factor **Z**	0.1	0.16	0.24	0.36
Horizontal Seismic Coefficient **Ah**	0.034	0.054	0.082	0.122
Base Shear **Vb in kN**	2391	3826	5738	8608
Moment **M in kN-m**	38256	61210	91815	137723

For Silt and Clay, time period is less than 0.67 sec, so Sa/g= 2.50

Table -4: Code analysis for Silt/Clay

Zone	II	III	IV	V
Sa/g	2.50	2.50	2.50	2.50
Response Factor **R**	5	5	5	5
Importance Factor **I**	1.5	1.5	1.5	1.5
Zone Factor **Z**	0.1	0.16	0.24	0.36
Horizontal Seismic Coefficient **Ah**	0.038	0.060	0.090	0.135
Base Shear **Vb kN**	2637	4219	6329	9494
Moment **M kN-m**	42194	67511	101267	151900

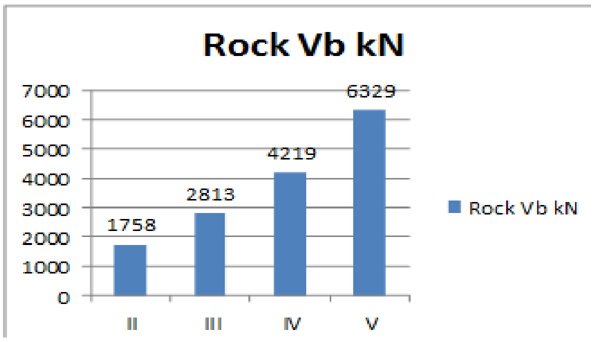


Figure 6 Base Shears for Rock

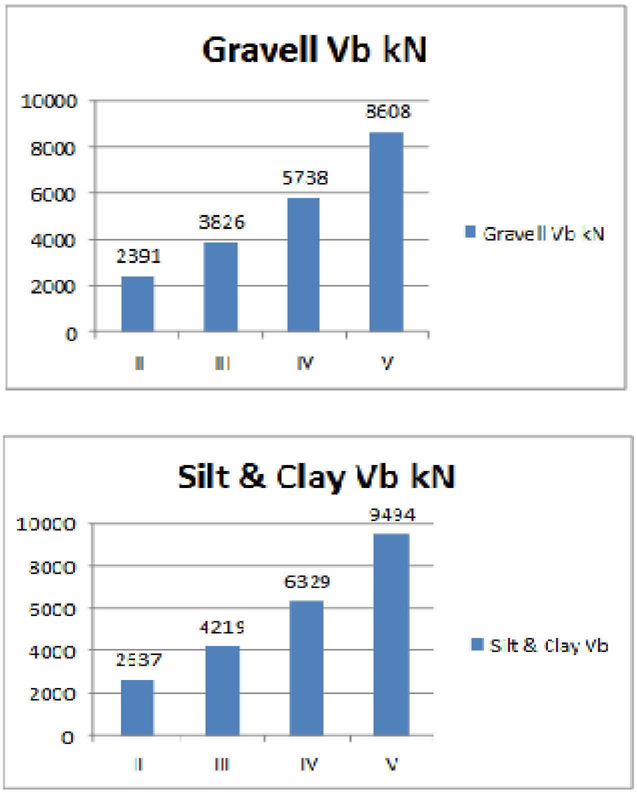


Figure 7 –Base Shear for Gravel Silt and Clay

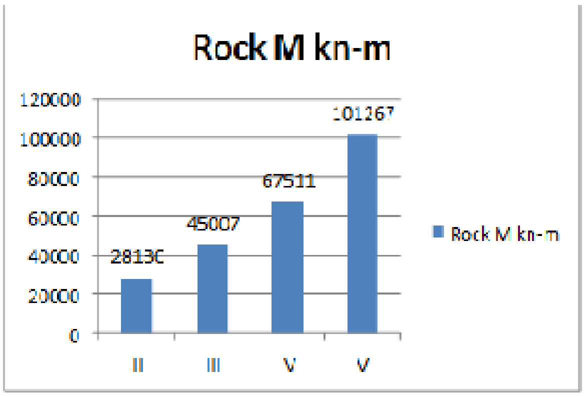


Figure 8 –Moment for Rock

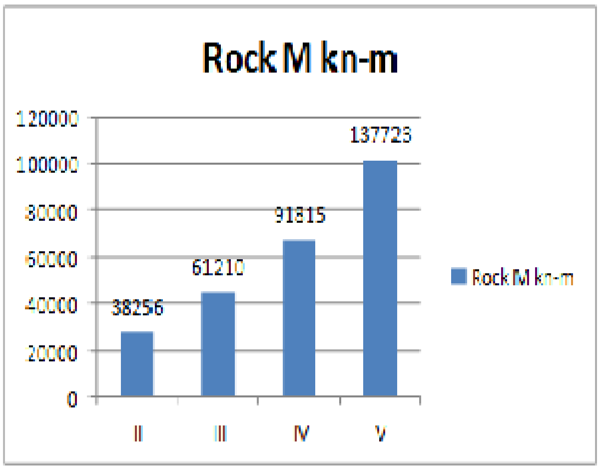


Figure 9 –Moment For Gravel

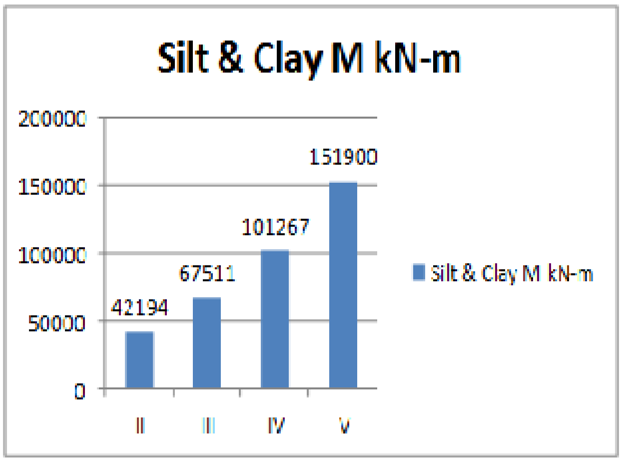


Figure 10 –Moment for Silt/Clay

4.2 As per Force Based And Displacement Based Design

Force Based:

Table -5: FBD for Rock

	M	A	F = m*a
Zone II	7168618.6	0.025	179215.47
Zone III	7168618.6	0.040	286744.74
Zone IV	7168618.6	0.060	430117.12
Zone V	8168618.6	0.090	645175.67

Table -6: FBD for Gravel

	Mass	Acceleration	F = m*a
Zone II	7168618.6	0.034	243733.03
Zone III	7168618.6	0.054	387105.4
Zone IV	7168618.6	0.082	587826.73
Zone V	8168618.6	0.122	874571.47

Table -7: FBD for Silt/Clay

Zone II	7168618.6	0.038	272407.5
Zone III	7168618.6	0.060	430117.12
Zone IV	7168618.6	0.090	645175.67
Zone V	8168618.6	0.135	967763.51

Displacement Based:

Table -8: DBD for Rock

	K	**Δ**	F = K***Δ**
Zone II	$1.78*10^6$	0.02	35600
Zone III	$1.78*10^6$	0.04	71200
Zone IV	$1.78*10^6$	0.07	124600
Zone V	$1.78*10^6$	0.1	178000

Table -9: DBD for Gravel

	K	**Δ**	F = K***Δ**
Zone II	$1.78*10^6$	0.025	44500
Zone III	$1.78*10^6$	0.045	80100
Zone IV	$1.78*10^6$	0.065	115700
Zone V	$1.78*10^6$	0.1	178000

Table -10: DBD for Silt/Clay

	K	**Δ**	F = K***Δ**
Zone II	$1.78*10^6$	0.03	53400
Zone III	$1.78*10^6$	0.05	89000
Zone IV	$1.78*10^6$	0.07	124600
Zone V	$1.78*10^6$	0.1	178000

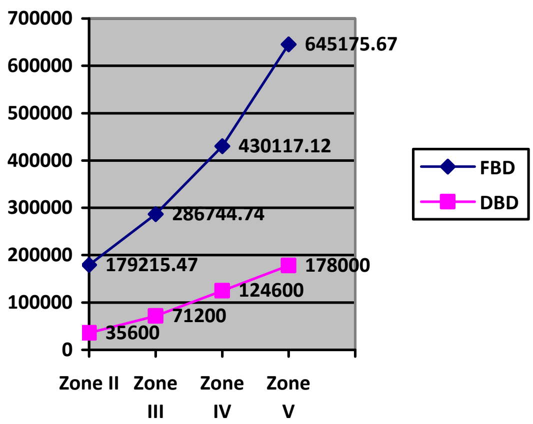


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Figure 11 –FBD and DBD for Rock

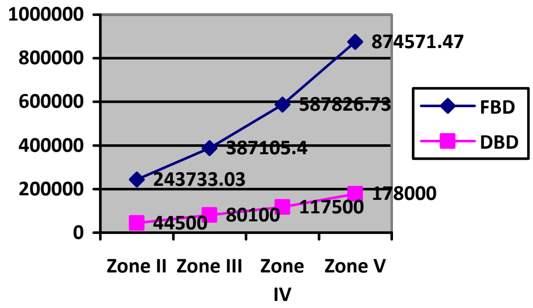

Figure 12 –FBD and DBD for Gravel

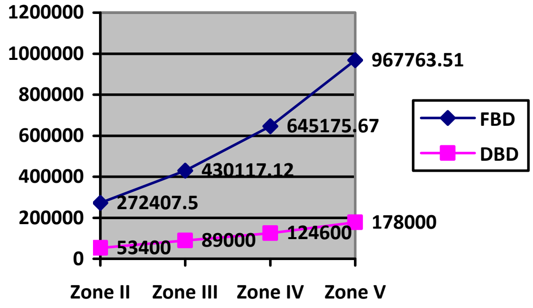

Figure 13 –FBD and DBD for Silt/Clay

4.3 For occurred Earthquakes

Table -11: Earthquake force Along X-Axis

	Zone II	Zone III	Zone IV	Zone V
Area in m^2	4.39	4.39	4.39	4.39
Moment of Inertia I in m^4	3.03	3.03	3.03	3.03
Height H	16	16	16	16
Section modulus of deck Z	2.34	2.34	2.34	2.34
Section modulus of pier Z_1	1.2	1.2	1.2	1.2
Deal load in Kgs	759097.8	759097.8	759097.8	759097.8
Live load in Kgs	6409520.8	6409520.8	6409520.8	6409520.8
Total load in Kgs	7168618.6	7168618.6	7168618.6	7168618.6
Stiffness K in kN-m	1.78	1.78	1.78	1.78
Structural frequency ω rad/sec	4.98	4.98	4.98	4.98
Damping factor ξ	0.05	0.05	0.05	0.05
Acceleration a in m/sec²	0.21	0.23	0.55	1.04
Earthquake force F_0 in kN	1563.82	1718.75	4095.71	7670.15
Time period t in sec	4	5	13	23
Frequency f in rad/sec	0.25	0.2	0.077	0.043
Seismic wave frequency ω1 in rad/sec	1.57	1.26	0.48	0.27
Frequency ratio r	0.32	0.25	0.096	0.054
Statical displacement in mm	$8.8*10^{-3}$	$9.64*10^{-3}$	0.023	0.043
Dynamic displacement in mm	$9.79*10^{-3}$	$9.95*10^{-3}$	0.023	0.043
Maximum shear V kN	1735.54	1767.52	4096	7660.7
Maximum moment M in kN-m	27.77	28.28	65.53	122.57
Maximum Stress f1 in kN/m²	23.14	23.57	54.47	102.14

Table -11: Earthquake force Along Z-Axis

	Zone II	Zone III	Zone IV	Zone V
Area in m^2	4.39	4.39	4.39	4.39
Moment of Inertia I	104.26	104.26	104.26	104.26
Height H	16	16	16	16
Section modulus of deck Z	19.55	19.55	19.55	19.55
Section modulus of pier Z_1	2.1	2.1	2.1	2.1
Deal load in Kgs	759097.8	759097.8	759097.8	759097.8
Live load in Kgs	6409520.8	6409520.8	6409520.8	6409520.8
Total load in Kgs	7168618.6	7168618.6	7168618.6	7168618.6

Stiffness K in kN-m	6108.98	6108.98	6108.98	6108.98
Structural frequency ω rad/sec	29.2	29.2	29.2	29.2
Damping factor ξ	0.05	0.05	0.05	0.05
Acceleration in m/sec²	0.21	0.23	0.55	1.04
Earthquake force F_0 in kN	1563.82	1718.75	4095.71	7670.15
Time period t in sec	4	5	13	23
Frequency f in rad/sec	0.25	0.2	0.077	0.043
Seismic wave frequency ω1 in rad/sec	1.57	1.26	0.48	0.27
Frequency ratio r	0.054	0.043	0.016	$9.24*10^{-3}$
Statical displacement in mm	$2.56*10^{-4}$	$2.8*10^{-4}$	$6.7*10^{-4}$	$1.25*10^{-3}$
Dynamic displacement in mm	$2.56*10^{-4}$	$2.8*10^{-4}$	$6.7*10^{-4}$	$1.25*10^{-3}$
Maximum shear V in kN	1563.89	1710.5	4093.02	7636.23
Maximum moment M in kN-m	25.02	27.37	65.49	122.18
Maximum Stress f1 in kN/m²	11.91	13.03	31.18	58.18

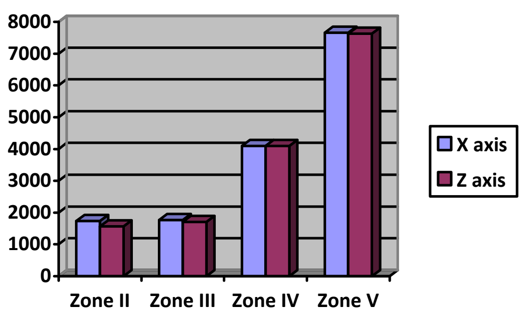

Figure 14 – Shear force along X axis and Z axis

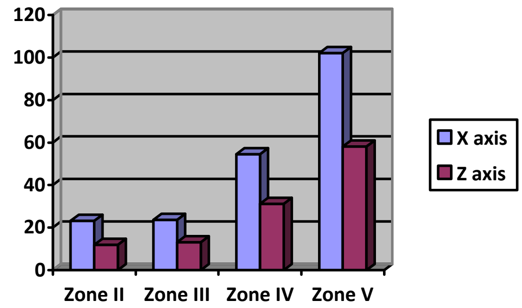

Figure 15 –Moment along X axis and Z axis

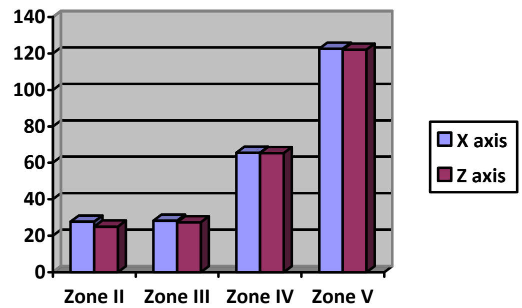

Figure 14 –Stress along X axis and Z axis

5. CONCLUSIONS.

From different a analysis in different Zones we can conclude that,

- From Code 1893 analysis, we can see, as the Zone increases the Horizontal Seismic Coefficient, Base Shear and Moment Increases for each type of soil.
- When we compare with soil conditions Soft soil experiences more shear force and moment when compared with other two types of soil. Rock is most suitable for construction.
- From FBD and DBD, it is clear that, no where the structure passes Displacement based design irrespective of soil and zones.
- From occurred earthquakes its shows that the structure will be more stable when the forces is along Z-Axis. And the structure can with stand the force of Zone IV, even though it was designed for Zone II.

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