

A Study on ‘Golden Ratio’ (ϕ) and its’ Implications in Structural Engineering

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ABSTRACT: There is a common mathematical ratio found in nature that can be used to create pleasing natural looking compositions, we call it as ‘Golden Ratio’, although it’s also known as golden mean. 20th century architects and artists like Le Corbusier and Dali, often advocated use of golden ratio through their work. The Ratio, i.e. 1.6180339..., can be eventually reached by dividing Fibonacci numbers, and the curve that we obtain out of it, is called golden curve, the occurrence of which, can be noticed many times, in nature.

In this trial, our aim is to investigate whether the property of ‘golden ratio’ plays any important role in behaviour of a structure. For, finding out about the same, our primary approach will be modelling the structures, abiding golden ratio, in ETABS and subjecting it to Earthquake loads and simultaneously modifying working models of same, and subjecting it to acceleration forces, and measuring its response. The response of models on parameters of Base Shear, Story Displacement and Story Drift were measured.

KEYWORDS: Golden Ratio, Seismic Design, Structural Stability, ETABS

I. INTRODUCTION

In mathematics, two quantities are in the golden ratio if their ratio is the same as the ratio of their sum to the larger of the two quantities. The figure on the right illustrates the geometric relationship. Expressed algebraically, for quantities a and b with $a > b > 0$,

$$\frac{a+b}{a} = \frac{a}{b} \stackrel{\text{def}}{=} \varphi,$$

Where the Greek letter ‘phi’ represents the golden ratio. It is an irrational number that is a solution to the quadratic equation $x^2 - x - 1 = 0$, with a value of:

$$\varphi = \frac{1 + \sqrt{5}}{2} = 1.6180339887 \dots$$

Mathematicians since Euclid have studied the golden mean and an used these properties to golden rectangles and pentagons. The idea has later been used to analyse markets and even natural patterns. Golden ration also appears a lot in nature, including spiral arrangement of leaves and petals in plants.

Artists and architects in twentieth century like le Corbusier and Salvador Dali started using golden ratio in their projects, believing them to be aesthetically pleasing. The use can also be noted in famous sites like Notre dame cathedral in Paris, France and marvels like Taj Mahal at Agra, India.

In this paper, the property and philosophy of golden ratio is tested against seismic accelerations, to check how a structure modelled on lines of golden ratio will perform better, if it’ll perform better.

Paper is organized as follows. Section II Related work that was referred. Section III elaborates the methodology as in how the models were selected and what is the procedure of modelling and analysing a structure on ETABS. Section IV presents experimental results showing the results of analysis. Finally, Section V presents conclusion.

II. RELATED WORK

A. P. Fantilli and B. Chiaia (2013) in their study they put forward a conjecture, in particular, Phi (1.618), which is an irrational number, appears when the average of crack spacing of Reinforce Concrete ties and beams is observed at different scales. This notion is authenticated by the results of a tension-stiffening model capable of predicting both the crack width and also the crack spacing noted during the tests. To put it in other words, it can be said that the essentiality of the golden ratio in the crack pattern of RC member had significant physical meanings and sheds some light on the existence of a size-effect law of spacing in cracks. The main advantage of this law lies in predicting the probability of appearance of crack pattern in large structures without knowing the performance of the material but just by testing the prototypes of scaled down lower dimensions. A. Carpinteri, B. Chiaia and G. Ferro (1995) have reported in their study of their observation on micro-cracks on region undergoing tension in a RC beam. The study clearly shows how the newly developing micro-crack follow fractal geometry patterns, which can be derived from Fibonacci sequence and phi (1.618). They also noted that such cracks are more prominent in small scale specimen, whereas for large scale the disorder is not prominently visible, also, the size of the cracks and defects and other heterogeneities are being limited.

III. METHODOLOGY

III) A) Selected Grids 1) The control model of square grids is created. A 4 m x 4 m grid with bay width of 5m each. The analysis done on this model is considered as the control figures. The model was subjected to seismic loads as well as regular dead and live loads.

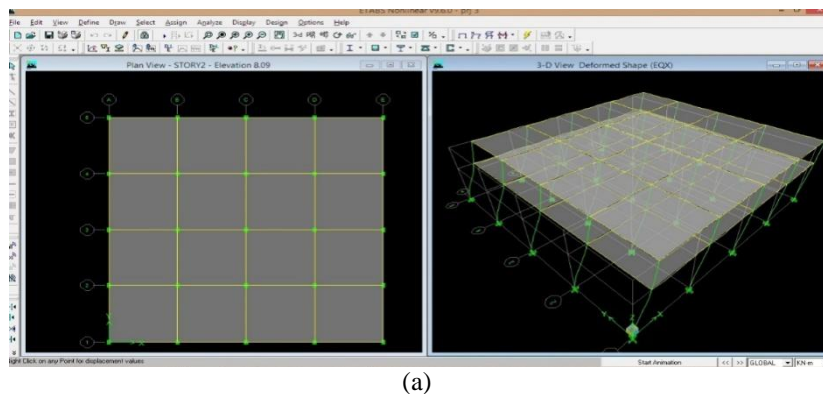


Fig.1 (a).Screen capture of standard 4m*4m Grid (used as control specimen)

2) For 2nd model, the golden ratio format was applied. The grid pattern was changed such that the outer bays are 0.618 times the inner bays. The updated bay lengths were 3.83m x 6.17m x 6.17m x 3.83m. Same as previous, the 2nd model too was subjected to seismic loads.

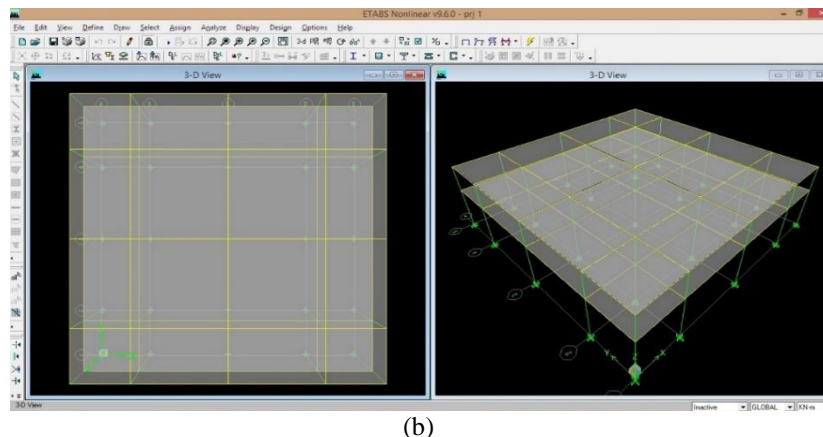
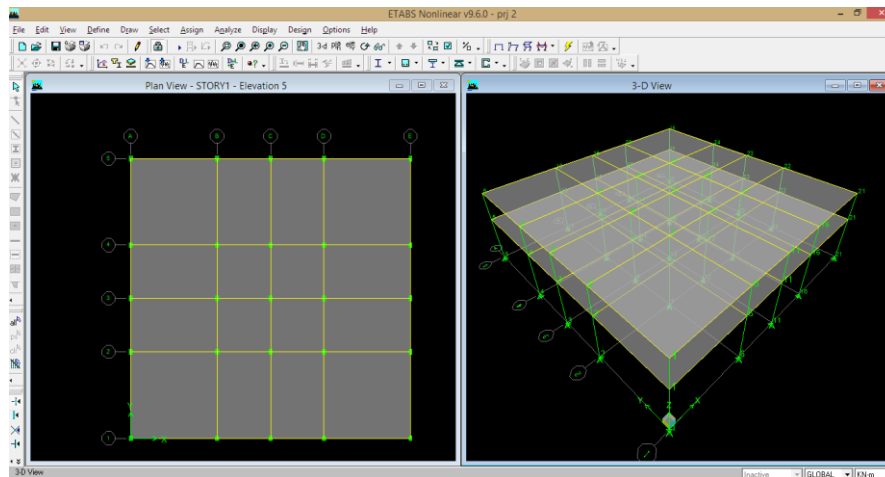


Fig.1 (b).Screen capture of updated Golden grid, with smaller bays aligned outwards

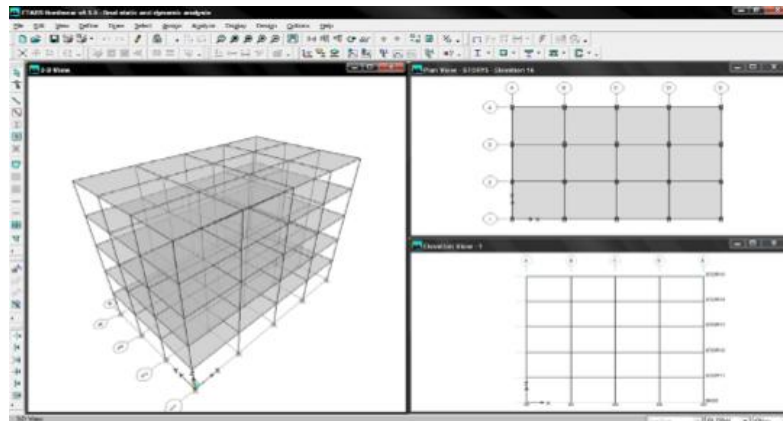
3) For 3rd model, again, the golden ratio format was applied. The grid pattern was changed such that the inner bays are 0.618 times the inner bays. The updated bay lengths were 6.17m x 3.85m x 3.85m x 6.17m. Same as previous, the 3rd model too was subjected to seismic loads.



(c)

Fig.1 (c).Screen capture of updated Golden grid, with wider bays aligned outwards

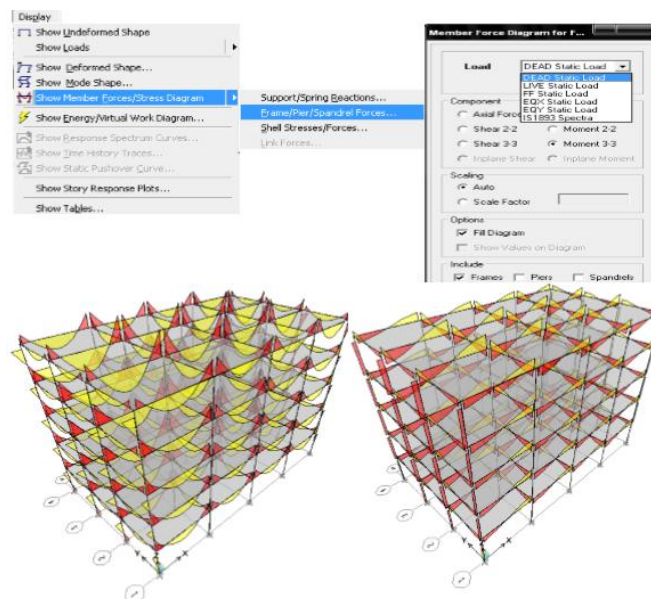
III) B) Modelling Using Etabs 1) Open the ETABS Program. 2) Check the units of the model in the drop-down box in the lower right-hand corner of the ETABS window, click the drop-down box to set units to KN-m. 3) Click the File menu > new model command (Note: we select No because this first model you will build). 4) The next form of Building Plan Grid System and Story Data Definition will be displayed after you select NO button. (Set the grid line and spacing between two grid lines. Set the story height data using Edit Story Data command) 5) Define the design code using Options > Preferences > Concrete Frame Design command. This will Display the Concrete Frame Design Preference. 6) Click the Define menu > Material Properties. Add New Material or Modify/Show Material used to define material properties. 7) Define section columns and beams using Define > Frame section. Define beam sizes and click Reinforcement command to provided concrete cover. Define column sizes and click Reinforcement command to provided concrete cover and used two options Reinforcement checked or designed.8) Define wall/slab/deck. To define a slab as membrane element and one way slab define using special one way load distribution.9) Generate the model. Draw beam using Create Line Command and draw column using Create Column command.Slab is created using 3 options in which 1st draw any shape area, 2nd draw rectangular area and 3rd create area in between grid line.10) Define various loads (Dead load, live load, Earthquake load). Dead Load: self-weight multiplier is used 1 to calculate dead load as default. Live load or any other define load. 1st select the member where assign this load than click the assign button. Assign point load and uniform distributed load. Select assigning point or member element than click the assign button.11) Assign support condition Drop-down box in the lower right-hand corner of the ETABS window, Select only bottom single storey level to assign fixed support using assign > Joint/Point>Restrain (Support) command. 12) In building, slab is considered as a single rigid member during earthquake analysis. For that, all slabs are selected first and apply diaphragm action for rigid or semi rigid condition. 13) Mass source is defined from Define > mass source command. (As per IS: 1893-2002) 25% live load (of 3 KN/m²) is considered on all floor of building except at roof level.14) Run analysis from Analysis > Run Analysis command. In ETABS, dead load and other loads are shown from table.



(a)

Fig.2 (a).Example of modelled structure using ETABS

III) C) Time Period and Mode Participation Factor 1) Static time period base on the IS 1893 is $0.075H^{0.75} = 0.6$ sec. 2) Dynamic time period as per ETABS analysis is 0.885 sec in X direction and 0.698 sec in Y direction. 3) Time period is shown in ETABS from Display > Show Mode Shape. 4) Bending moment and shear force diagram is shown from Display > Show Member Forces > Frame/Pier/Spandrel Forces command 5) Mass participation factor is shown from Display > Show Table > Model Information > Building Model Information > Model Participating Ratio. 6) Bending moment and shear force diagram is shown from Display > Show Member Forces > Frame/Pier/Spandrel Forces command.



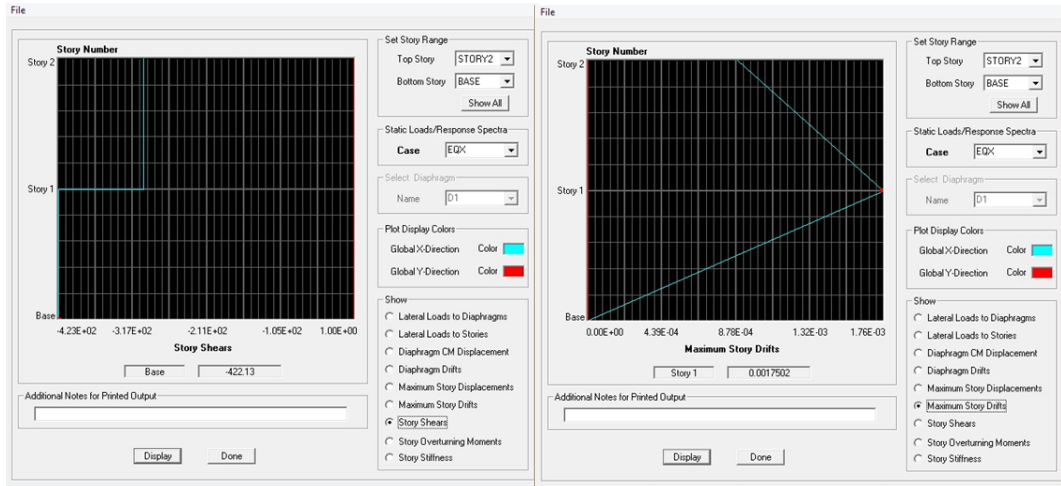
(b)

Fig.2 (b).Bending Moment and Shear Force Diagram example using ETABS

III) D) Seismic Force Calculation as per IS: 1893-2002 1) Static Method. 2) Define static load from Define > Static load command. 3) Press modify lateral load to shown below figure and assign various value as per IS 1893.

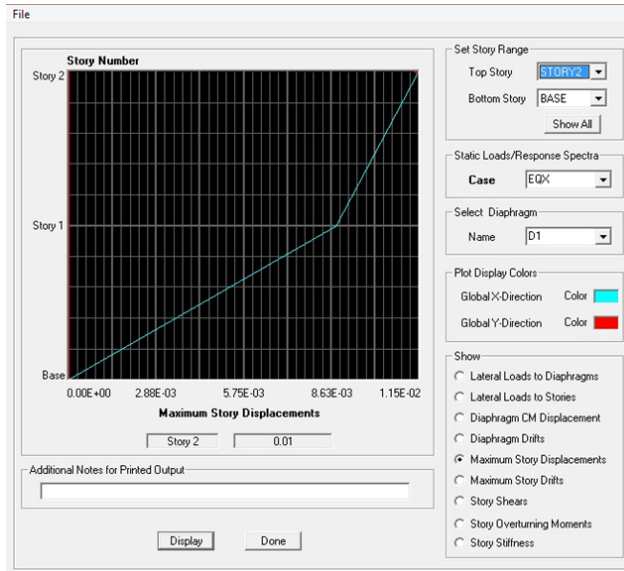
IV. EXPERIMENTAL RESULTS

Given below are analysis results for said models. Figure 3 (a, b and c) are showing the Story shear, maximum story drift and maximum story displacement respectively for the controlled specimen.



(a)

(b)



(c)

Fig.3. Analysis Results for control specimen (a) Story Shears (b) Maximum Story Drift (c) Maximum Story Displacements

Figure 4 (a, b and c) are showing the Story shear, maximum story drift and maximum story displacement respectively for the structure modelled as per golden ratio, with smaller bays aligned outwards. As it is evident, Improvements can be noted in base shear readings, while displacement and drift readings have not shown a significant improvement.

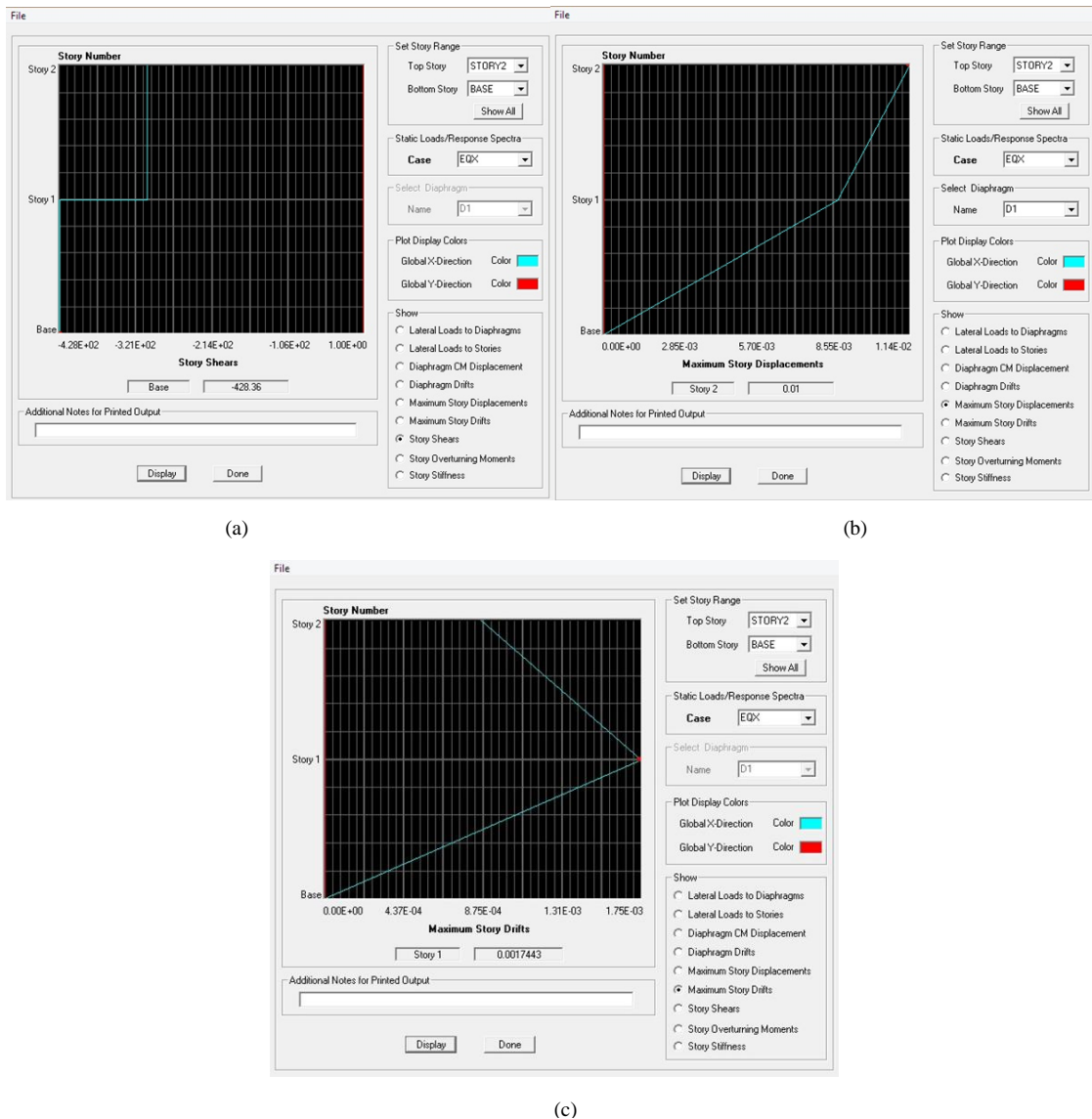
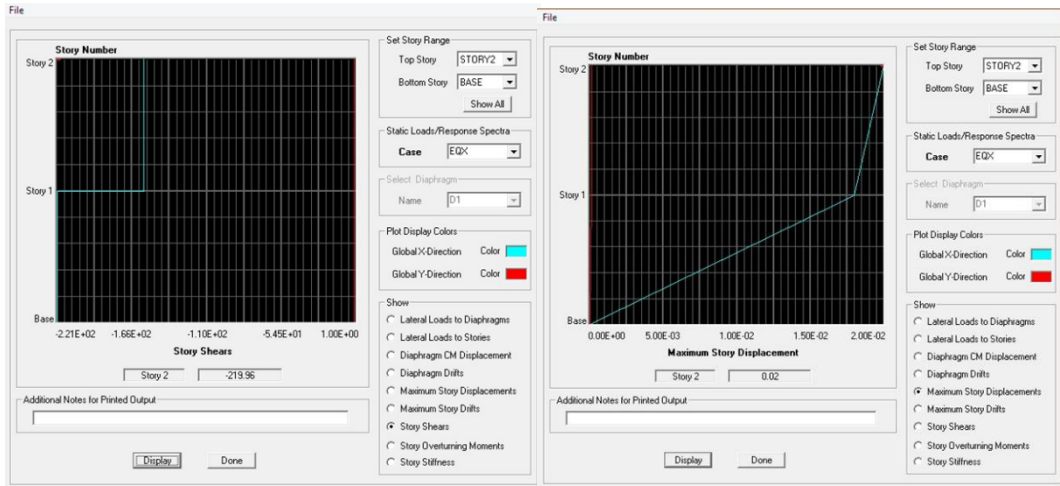


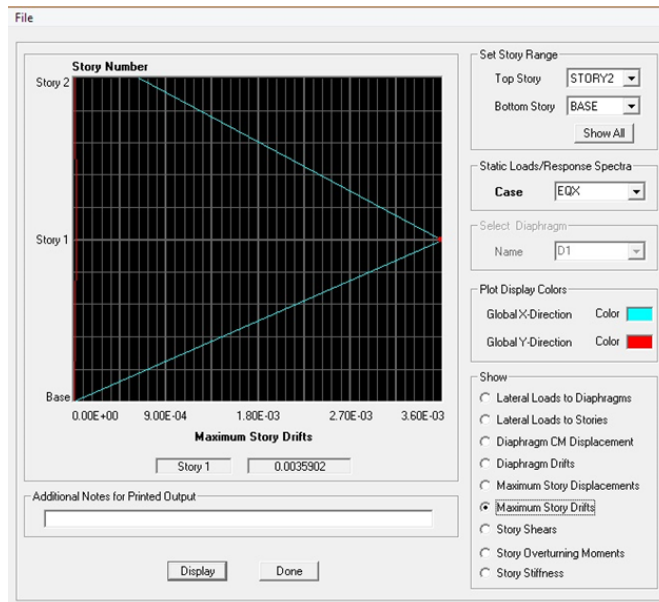
Fig.4 Analysis Results for Golden Ratio Specimen with Smaller Outer Bays (a) Story Shears (b) Maximum Story Displacement (c) Maximum Story Drifts

Figure 5 (a, b and c) are showing the Story shear, maximum story drift and maximum story displacement respectively for the structure modelled as per golden ratio, with wider bays aligned outwards. As in the previous case, Improvements can be noted in base shear readings manifolds, while even here, the displacement and drift readings have not shown a significant improvement.



(a)

(b)



(c)

Fig. 5 Analysis Results for Golden Ratio Specimen with Wider Outer Bays (a) Story Shears (b) Maximum Story Displacement (c) Maximum Story Drifts

V. CONCLUSION

1. It was observed that, better results were obtained when golden ratio principal is used in the simplified model.
2. Model 3 analysis gave a better result, than other grid models.
3. Golden ratio efficiency, when in case of seismic loading is observed in given models..



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