Analysis of Compound Column-Based Supporting Structures Used in Suburban Railway Transport System: Use of Stiffener Plates

Herin Savla, Neel Sanghvi, Saurabh Rasal, and Vinayak H. Khatawate

Abstract This paper documents a comparative numerical analysis aimed at verifying the application of stiffener plates in a compound column, which is being used as a supporting member at multiple railway stations in the Mumbai Suburban Railway Network. Stiffener plate is a term used for a group of plate-like structural elements that are used to increase the rigidity of a beam or column. These stiffener plates are installed at specific locations in the column to decrease mainly the total deformation, equivalent stress, equivalent elastic strain, and the shear stress. Linear and non-linear analyses were performed for the compound column, both with and without the presence of the stiffener plates. It was concluded that with a 3% increase in the weight of the structure, the total deformation decreases by 8% and the equivalent stress decreases by 28%.

Keywords Stiffener · Safety · FEA · Column · Structural engineering

1 Introduction

The design of a railway station is a complex process, primarily because major repairs can incur very large costs, and also because these areas witness a large flux of people [1]. The capability of the railway station to safely handle a large volume of people during technical snags and natural calamities is also an aspect which has to be considered during railway station design [2]. In cities with high population and complex railway transit systems, e.g. Mumbai, New York City, London [3, 4], etc., railway stations often have to accommodate a very large number of people at a given time, especially during the peak hours. And the land area available for construction is often limited.

Thus, railway stations accommodate certain features in their design which help to accommodate a large number of people at a given time. One such common feature

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is the construction of an upper level above the ground level to place features like cafeterias, ticket counters and other places of interest. This structural feature prevents overcrowding at the railway stations [5]. In the Mumbai suburban railway network, which is made of approximately 430 km of railway track, this feature is observed at multiple railway stations—Borivali, Andheri and Goregaon to name a few. The provision of a second level helps to keep the population density low.

This second or upper level can be described as a large slab of concrete with columns passing through it. Given the average density of masonry [6], the mass and hence weight of this slab will be quite high. The columns or stationary vertical members used to support this second level will have to be strong enough to successfully bear this load without large deformations. Moreover, this loading will be of a complex and dynamic nature due to movement of people and the presence of wind and other such factors [7].

The supporting columns that were observed at Andheri and Goregaon railway stations were of absolute metal type, using no concrete or other such material. The columns were essentially two I-beams fused together such that their longitudinal axes were coinciding and they had their end faces in the same horizontal plane but the cross-sections were perpendicular to each other. The feature of the column which is the major interest in this experiment is the use of stiffener plates in the columns [8, 9]. Stiffeners are secondary plates or sections which are attached to beam webs or flanges to stiffen them against out of plane deformations [9, 10]. An image of a part of the above-described compound column is shown in Fig. 1. Stiffener plate is basically an example of a structural element. The fundamental goal of a structural element is to function as a part of a given structure; although in many cases, structural elements are used to increase the strength of a structure and its inherent safety. Two interesting features about these plates are that the thickness is always much smaller compared to the length and width and that the forces applied on them generate stresses whose resultants lie exclusively in a plane normal to the plate thickness. Stiffener plates are used widely in marine applications especially for hull girder construction [11, 12].

The use of stiffeners contributes additional strength to the web by ensuring that the web does not laterally buckle or cripple due to application of heavy concentrated load [13]. The horizontal intermediate stiffeners are used to increase the buckling strength of the web and these are located in the compression zone [14]. They prevent the web from bending laterally [15, 16].

2 Objectives

The authors's principle objective is to perform a comparative study aimed at verifying the application of stiffener plates in a compound column while applying basic concepts of FEA to solve this real-life engineering problem. Their aim is to also understand the application and importance of FEA in structural engineering while studying and analysing an example of practical application of structural engineering.

Fig. 1 Image of lower portion of column observed at Andheri station

3 Methodology

The software used for designing the compound columns both with and without stiffener plates is SOLIDWORKS 2018. The subsequent analysis of these columns was done by using FEA. To create the 3D CAD model of this column, the authors paid a visit to the Andheri railway station to measure and note down the required dimensions. For performing the analysis, structural steel was assigned as the material to this column design. A suitable mesh was applied, fixed supports were selected and a remote force was added. Then, the analysis to calculate the values of total deformation, directional deformation, equivalent elastic strain, shear elastic strain, shear stress, equivalent stress, and maximum shear stress was performed on both columns(with and without stiffener plates). Figures 2 and 3 given below show the meshed CAD model of the compound columns with and without the stiffener plates.

4 Design Calculations

In this comparative study, two versions of the column are considered. The first version is the basic compound column. The second column has stiffener plates installed in

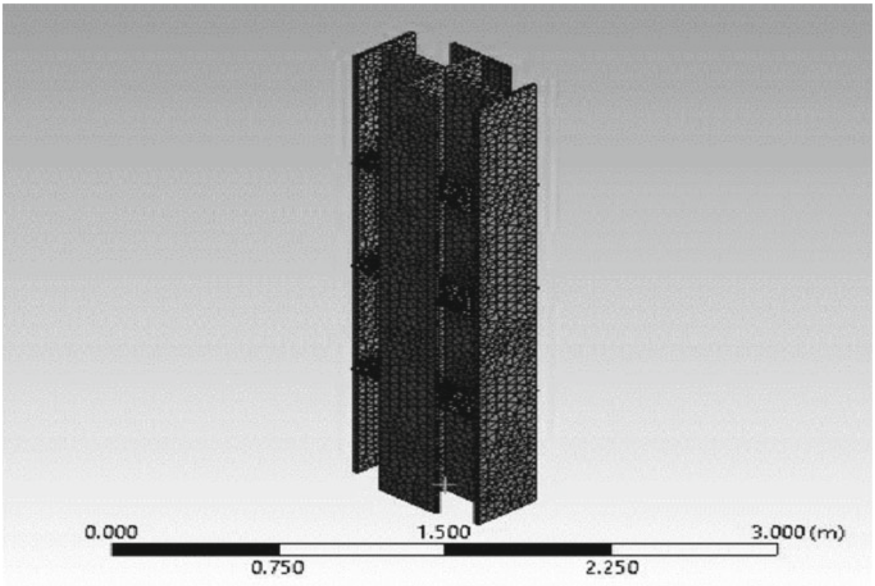

Fig. 2 Meshed body for compound column with stiffener plates

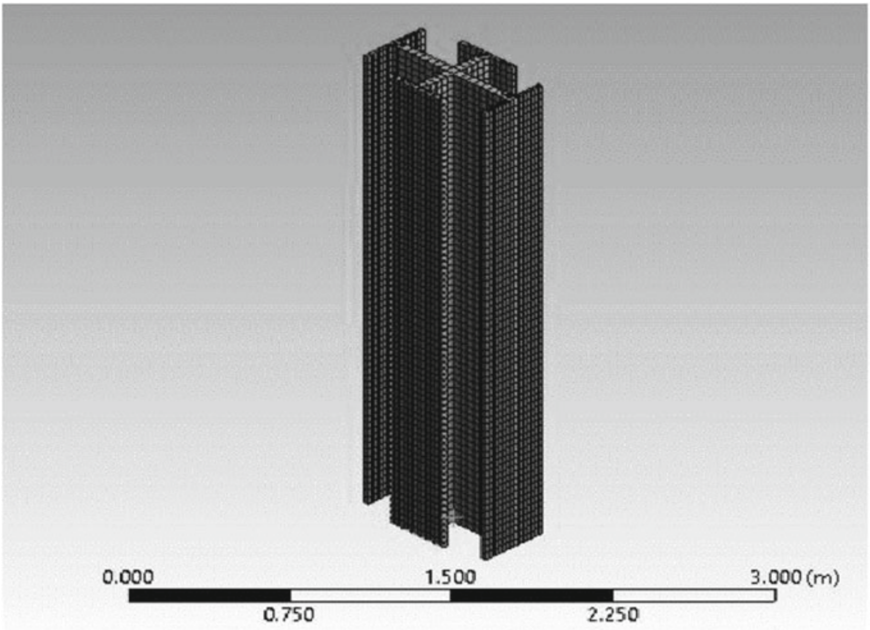

Fig. 3 Meshed body for compound column without stiffener plates

the plane perpendicular to the longitudinal axis of the column. Four stiffener plates are installed in one horizontal plane. The stiffener plates are taken to be manufactured with the same material as that of the column.

After a basic survey of Andheri railway station, the initial conditions are decided such that a representative computer model of the system can be developed. By means of measurement and suitable estimates, it is estimated that one compound column is responsible for bearing the weight of a part of the first level having an area of 3 m × 8 m. Slab thickness of the first level is considered to be 25 cm.

The column observed at the before-mentioned location consists of 11 segments (one segment implies one stiffener plate group and a certain length of continuous column). Due to increased computational cost, the analyses are restricted to representative model of the column consisting of three such segments. This gives rise to a scaling factor of 3/11 in the design calculations. The average density of masonry is taken as 2000 kg/m^3 [6].

By making use of the appropriate mathematical formulae, the load exerted by a part of the first level on the column is calculated to be 117.72 kN. This is multiplied by the scaling factor to give a value of 32.105 kN which is increased to 40 kN to account for the presence of people on the bridge and also the presence of various structures like ticket counters, ATMs, and fast food joints on the first level.

5 Results and Discussion

The authors have performed a non-linear analysis in 20 steps of 2 KN each, while keeping large deflection mode ON. The authors have taken *Y*-axis as the axis along the height of the column, *Z*-axis as the axis perpendicular to the railway track, and *X*-axis as the axis parallel to railway track. A total of 40 kN load was applied.

It is clear from Table 1 that the addition of stiffener plates to the compound column has the desired result of decrease in the values of stress and deformation experienced by the column. The linear analysis shows that there is 8.209% decrease in total deformation and 28.316% decrease in equivalent stress on addition of stiffener plates. The non-linear analysis shows that there is 8.84% decrease in total deformation and 28.36% decrease in equivalent stress on addition of stiffener plates. In Figs. 4 and 5, the authors have shown the results for von-Mises stress and total deformation of the linear analyses for both types of columns.

6 Conclusion

Linear and non-linear analyses were performed to study the effect of stiffener plate on the rigidity of the compound column. Linear analysis was performed by applying a static load of 40 KN whereas the non-linear analysis was performed by applying the same load but in 20 steps of 2 KN each. The force was applied at a calculated point

Table 1 Results of linear and non-linear analyses (DEC indicates decrease in corresponding quantity)

	Linear without stiffener	Linear with stiffener	Change (%)	Non-linear without stiffener	Non-linear with stiffener	Change (%)
Total deformation (m)	3.1816e−5	2.9204e−5	−8.209 DEC	3.2035e−5	2.9203e−5	−8.84 DEC
Deformation X (m)	6.1183e−6	2.5481e−6	−58.35 DEC	6.1185e−6	2.539e−6	−58.50 DEC
Deformation Y (m)	3.1735e−5	2.9098e−5	−8.31 DEC	3.1953e−5	2.9158e−5	−8.747 DEC
Equivalent elastic strain	5.602e−5	4.0156e−5	−28.32 DEC	5.605e−5	4.015e−5	−28.36 DEC
Shear elastic strain	2.102e−5	1.896e−5	−9.844 DEC	2.105e−5	1.907e−5	−9.36 DEC
Equivalent stress (Pa)	1.120e7	8.0313e6	−28.32 DEC	1.121e7	8.031e6	−28.36 DEC
Shear stress (Pa)	1.617e6	1.458e6	−9.84 DEC	1.619e6	1.467e6	−9.36 DEC
Maximum shear stress (Pa)	5.875e6	4.246e6	−27.74 DEC	5.879e6	4.246e6	−27.78 DEC

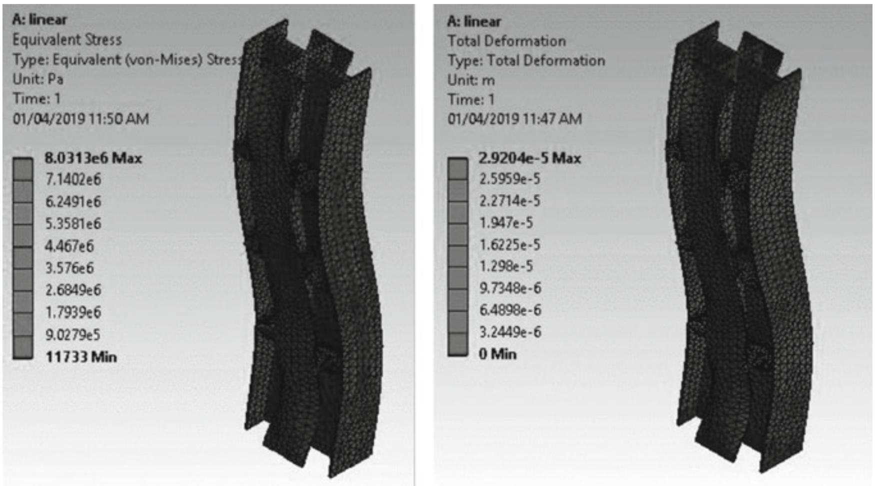

Fig. 4 Results for von-Mises stress and total deformation of linear analyses for columns with stiffener plates

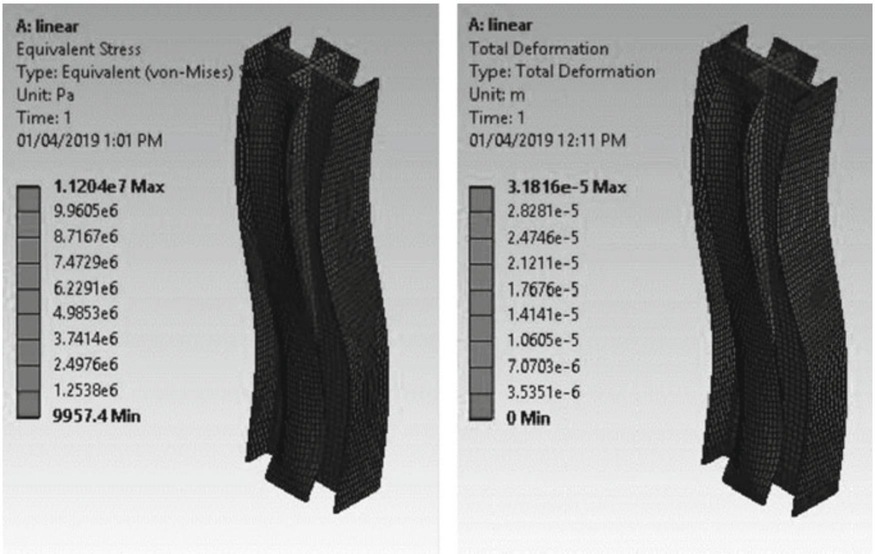

Fig. 5 Results for von-Mises stress and total deformation of linear analyses for columns without stiffener plates

as a remote force. The results were analysed and it was observed that the addition of stiffener plates increases the mass of the column by 3.04% but decreases the von-Mises stress by more than 28% and decreases the total deformation by more than 8%. Thus, it is effectively concluded that the addition of stiffener plates in the design of these compound columns is justified.

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