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# NUMERICAL ANALYSIS OF A FRAMED STRUCTURE SUBJECTED TO METRO RAIL LOADS

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**Abstract -** *The concept of metro bridge superstructure over building structures is considered an apt solution for the sprouting issues regarding the implementation of mass rapid transit projects due to scarcity of land. By designing the building structure as a supporting element to bear the metro superstructure loads, utilization of optimal space is possible. This study investigates the dynamic response of a framed structure subjected to metro superstructure loads. Specified columns in the building structure are subjected to metro super structure loads, rather than loading the entire structure. By considering these columns as the loading frame, static and dynamic analysis of the whole structure is carried out numerically. Response of the whole structure due to the application of static and dynamic loads from metro super structure on the loading frame is analysed using ANSYS 19.1. Response of the building structure under seismic loading, during the phase of metro train movement is also observed.*

***Key Words***: *Metro superstructure loads, building structure, dynamic analysis, seismic loading.*

## 1.INTRODUCTION

Metro transit is a type of high capacity public transport generally found in urban areas. One of the major risks in procurement and implementation of mass rapid transit projects is to manage the conflicts involving land acquisition. Land that is well connected to markets is especially scarce. The concept of metro bridge superstructure over building structures is considered an apt solution for the issue. By designing the building structure as a supporting element to bear the metro super structure loads, utilization of optimal space is possible. In the present proposal, a building structure is considered as the supporting element (substructure) of metro rail structure, i.e. the piers of the metro rail structure is replaced by a building structure. The building structure is designed to bear metro superstructure loads. The concept of the proposal is to place the metro bridge girders and to continue other corresponding works of the metro superstructure after the completion of building structure construction. Rather than loading the entire supporting elements of the building structure, specified columns are subjected to metro superstructure loads. These specified columns which are subjected to metro superstructure loads, are considered as the loading frame. A three column type loading frame and concrete wall loading frame located at centre and periphery of the building structure is considered for the study. The concept of a three column loading frame subjected to metro superstructure loads is shown in Fig-1

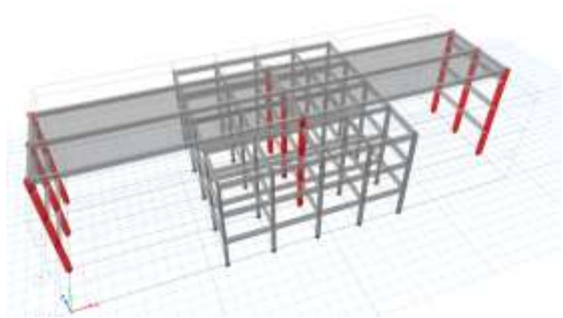

**Fig-1**: Three column loading frame subjected to metro loads

## 2. BUILDING STRUCTURE

### 2.1 Geometry of the Problem

The building structure to be analyzed was modelled in ANSYS Workbench 16.0. The size of the building structure considered is (16×16)m. The building structure was modeled with features similar to Kochi metro rail structure. The height of metro pillars from pile cap top to pier head provided for the Kochi metro project was nearly 7m. Considering the disparity in ground elevation (which is determined from the terrain), the structure was modeled as a three storied building with a total height of 9m (each storey provided 3m height). Columns of the building structure were placed at a distance of 4m (centre to centre) considering usual room size for buildings. Single hammer head pier provided for Kochi metro project is replaced by three columns and then by concrete wall successively, which is assumed to install in the framed structure. These particular columns and concrete wall (amongst other building columns), which is subjected to super structure loads are considered as the loading frame. The size of columns considered for metro superstructure loading in the building structure is (0.4×0.4)m, while other columns were provided with a size of (0.2×0.4)m. In the case of concrete wall considered for loading, width of 0.30m was provided. Beams for the building structure were provided with a size of (0.20×0.50)m. Since the width of deck provided is nearly 8m, the total width of loading frame is considered 8m (three columns with 4m centre to centre distance). Load from the super structure is applied on the loading frame (through bearings), which is implemented by considering a solid body (platform) attached above the bearings and imposing the loads of the super structure on the solid body. The building frame structure with loading platform on top is shown in Fig-2

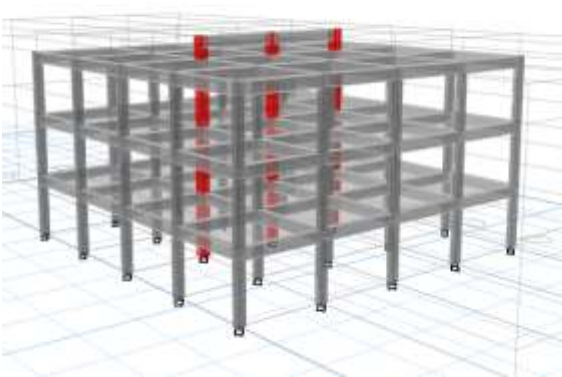

**Fig-2**: Building frame structure with loading platform on top

### 2.2 Modelling of the Problem

The physical problem was modelled as per the layout. Four models were considered. For model-I a three column loading frame located at centre of building frame is considered, for model-II a concrete wall loading frame located at centre of loading frame is considered, for model-III a three column loading frame located at periphery of building frame is considered and for model-IV a concrete wall loading frame located at periphery of building frame is considered. The four models are shown in Fig-3

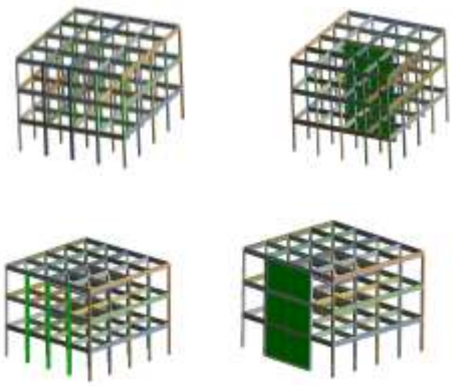

**Fig-3**: Four models of building structure

### 2.3 Material Properties

The properties of the reinforced concrete were assigned to building columns and beams. M40 grade concrete is assigned for columns and beams. Elastomeric bearings are provided in the space between the platform modeled (which is considered as the superstructure) and the loading columns in the building structure. The purpose of a bearing is to allow controlled movement and thereby reduce the stresses involved. Movement could be due to thermal_expansion or contraction or movement from other sources such as seismic activity. The vertical stiffness and damping values assigned for the model are referred from the study performed by Can Akogul [2] and Hitesh Bhure [4]. The material properties assigned are illustrated in table-1

**Table -1:** Material properties

| Material properties | Value |
|---|---|
| Density of concrete (kg/m$^3$) | 2500 |
| Coefficient of thermal expansion of concrete (/°C) | $1.4 \times 10^{-5}$ |
| Young's modulus of concrete (N/mm$^2$) | $3.6 \times 10^4$ |
| Poisson's ratio of concrete | 0.18 |
| Bulk modulus of concrete (N/mm$^2$) | $1.56 \times 10^4$ |
| Shear modulus of concrete (N/mm$^2$) | $1.27 \times 10^4$ |
| Grade of concrete | M40 |
| Longitudinal stiffness of elastomeric bearing (N/mm) | $1.14 \times 10^6$ |
| Longitudinal damping of elastomeric bearing (N-s/mm) | 50 |
| Spring length (mm) | 100 |

### 2.4 Connections, Meshing and Support Conditions

Fixed supports are considered below the columns. For providing the bearing, a spring is considered at the connection. Frictional connections are provided between the contact area of elastomer and girder (solid platform) because of the different materials used for the construction. In Finite Element Analysis (FEA), meshing is an integral part of analysis for that, the model is divided into small discrete regions called finite elements. The support conditions of the model is show in Fig-4

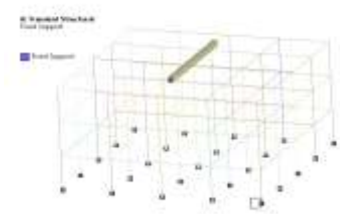

**Fig-4**: Support conditions

## 3. LOADING CONDITIONS

### 3.1 General

The design loads considered for the study primarily include loads from the metro super structure acting on the loading frame (installed in the building structure) and the loads acting on the elements of building structure (dead and live loads of the commercial building).

### 3.2 Loads from Metro Super Structure

The elementary loads considered for the analysis are static loads and dynamic loads. The loads from the metro super structure will be applied on the solid platform (assumed instead of super structure) located on top of the building model. Static loads include Dead Loads (DL), Live Loads (LL) and Super Imposed Dead Load (SIDL). The loads are specified from IRS Bridge Rules [6] for calculation of impact factor, force on parapet and foot path live loads. For performing static analysis, live load considered is the load of metro three car combination with an impact factor of 1.4 referred from IRS [6]. SIDL is divided into two parts i.e. SIDL variable and SIDL fixed. Only parapet load comes under SIDL fixed. Vertical reactions (V) on top of the supporting element due to static loads are referred from the study performed by Bharat Sharma [1]. The reactions on the supporting element considered is illustrated in table-2

**Table -2:** Reactions on supporting element

| Load cases | V (kN) |
|---|---|
| DL | 6930 |
| SIDL Fixed | 1304 |
| SIDL Variable | 2296 |

The dynamic load primarily considered is the train dynamic load. The response vibration of a stress wave induced by the track structure at the wheel rail interface was employed as the train dynamic load. The train load considered is as per Nagpur Metro Rail Corporation Limited (NMRCL) Design Basis Report (DBR) [8]. Three successive cars are considered in a train and the length of each car is 21.8m. Each car consists four axles and load of each axle is same i.e. 160 kN. Standard axle distance of Nagpur metro train is shown in fig-5


**Fig-5**: Standard axle distance of Nagpur metro train

Train dynamic load was calculated by determining the fourier series coefficient and the corresponding principal frequencies. The frequency range of the moving train load is finite and related to the train speed. To find out the dominant frequencies in a vast range of frequencies, Fast Fourier Transform (FFT) was performed. The dynamic load obtained after performing FFT and FFT loading in ANSYS is shown in Fig 6

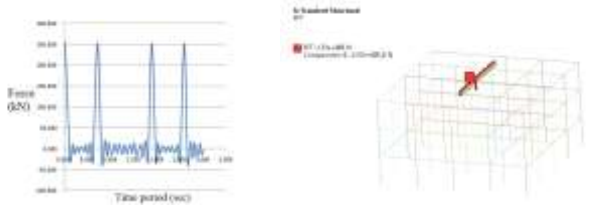

**Fig-6**: Dynamic load with FFT and loading in ANSYS

### 3.3 Building Structure Loads

The building structure considered for the study is a commercial one. The loads primarily include the Dead Loads (DL), Super Imposed Dead Loads (SIDL) and Live Loads (LL). The DL and LL considered for the study are as specified in IS 875 (Part I and II) -1987.

### 3.4 Seismic Loading

Response of the building structure subjected to seismic loading during the phase of train movement is observed. Time history analysis is performed for the analysis. Past earthquake response of EI Centro earthquake happened in 1940 was used for time history analysis. The total duration of earthquake response is 30 second. Seismic analysis of the structure considering 30 seconds consumes greater time. Since the maximum response of the earthquake is seen during the first 10 seconds, earthquake response data of first 10 seconds is considered for the analysis. The metro train passing time above the structure considered is 3 seconds. Time acceleration data of EI Centro earthquake is shown in Fig-7

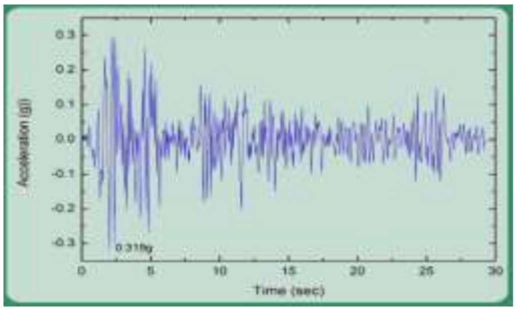


**Fig-7**: Time acceleration data of EI Centro earthquake

## 4. ANALYSIS AND RESULTS

### 4.1 Static Analysis

Static analysis has been performed considering three column loading frame located at centre of building structure. Static analysis has been performed in ANSYS and ETABS software to compare the results obtained from both softwares and check the precision, before performing dynamic analysis. The analysis has been performed for total deformation, total bending moment, column reaction and shear force. The total bending moment for static analysis performed in both softwares is shown in Fig-8.

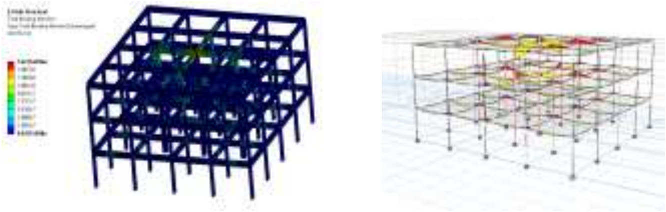

**Fig-8**: The total bending moment for static analysis

The results obtained from the static analysis using softwares ANSYS and ETABS have been compared. The maximum values for deformation, total bending moment, column reaction and shear force has been noticed for the same elements in the loading frame. The comparison of software results is illustrated in table-3

**Table -3:** Comparison of software results

| Description | ANSYS Result | ETABS Result | Variation (%) |
|---|---|---|---|
| Maximum column reaction (kN) | 7280 | 7163 | 1.61 |
| Maximum deformation (mm) | 11.72 | 12.5 | 6.66 |
| Maximum bending moment (kN-m) | 162 | 148 | 8.64 |
| Maximum shear force (kN) | 108 | 116 | 7.41 |

### 4.2 Dynamic Analysis

Transient (dynamic) analysis has been performed for all the four models. The analysis has been performed for total deformation, total bending moment, column reaction and shear force. The analysis results for total deformation for model-I&II is shown in Fig-9

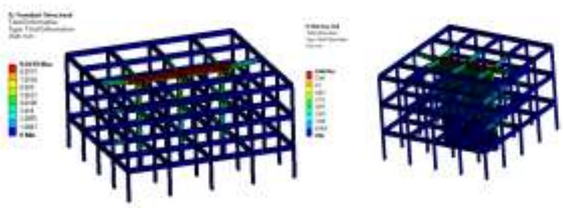

**Fig-9**: Total deformation results for model-I&II

The analysis results for total bending moment for model I&II is shown in Fig-10.

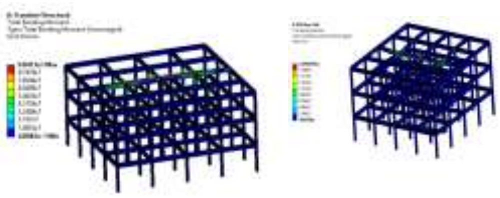

**Fig-10**: Total bending moment results for model-I&II

The results obtained from the transient analysis of the four models have been compared. Regarding the maximum deformation of the structure, comparatively lesser values were noticed for model II and model III. But the total bending moment revealed higher values for these models (II and III). Regarding the column reactions, not much variation in the values has been observed for all the four models. The summary of results for transient analysis is illustrated in table-4.

**Table -4:** Comparison of dynamic analysis results

| Description | Model I | Model II | Model III | Model IV |
|---|---|---|---|---|
| Maximum deformation (mm) | 9.04 | 6.06 | 9.76 | 7.88 |
| Maximum bending moment (kN-m) | 98.4 | 202 | 74.5 | 208 |
| Maximum column reactions (kN) | 3325 | 3325 | 3454 | 3331 |

### 4.3 Seismic Analysis

Seismic analysis has been performed for model I since the model is considered as the optimized model taking into account the transient analysis. Time history analysis has been performed on the model. Acceleration time data has been induced in the structure during the phase of train movement. The response of the building has been observed. The analysis has been performed for total bending moment, shear force and axial forces. The total bending moment for time history analysis is shown in Fig-11.

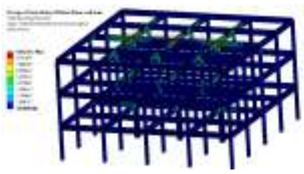

**Fig-11**: Total bending moment for time history analysis

From the results obtained from the seismic analysis of the building structure during the phase of train movement, it has been observed that not much variation in the values of bending moment, deformation and axial forces was noticed compared to the results of the transient analysis performed in the building structure. The comparison of results for seismic and dynamic analysis is shown in Table-5.

**Table -5:** Comparison of seismic and dynamic analysis

| Description | Seismic Analysis Result | Dynamic Analysis Result |
|---|---|---|
| Maximum column reaction (kN) | 3281 | 3325 |

| | | |
|---|---|---|
| Maximum deformation (mm) | 6.34 | 9.04 |
| Maximum bending moment (kN-m) | 98 | 98.4 |

## 5. CONCLUSION

The possibility of metro superstructure over building structure has been studied by performing a numerical analysis of building structure subjected to metro superstructure loads. In this study static, dynamic and seismic analysis has been carried out for total deformation, total bending moment, column reactions and total shear force for four different models, with loads of the metro superstructure applied to a three column frame and concrete wall respectively, located at centre and periphery of the building structure. Based on the results obtained the following conclusions are made

- Static analysis of the building structure has been carried out using software ANSYS and the results were compared with that obtained from the software ETABS. It has been observed that the percentage variation of results obtained from the static analysis of the structure using two different softwares for total deformation, total bending moment, maximum column reactions were less than 10%
- Transient analysis has been carried out for four different models. Maximum values for deformation, bending moment and column reaction has been observed in the loading frame of the building structure. Even though the deformation values for model II and model IV were less compared to other two models, very high moment values has been observed in the loading frame. Since the moment values observed were less for model I and model III compared to other two models, model I and model III were considered suitable models taking into account the transient analysis of the structure.
- Taking into account transient analysis of the models, model I was considered for seismic analysis. Seismic analysis has been carried out for model I and the maximum values for total deformation, total bending moment, total shear force and total axial force was observed in the loading frame. It was noticed that not much variation has been observed in deformation, bending moment and axial force values compared to that of transient analysis results.

## 6. FUTURE SCOPE

- Dynamic analysis of building structure considering loading frames on two peripheral areas of the structure
- Vibration isolation in the building structure using different techniques

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