# Parametric Analysis on Buildings with Connecting Corridors

Afiya V N

Research Scholar, Department of Civil Engineering, FISAT, Mahathma Gandhi University, Kerala
Email: afiyavn@gmail.com

***Abstract*—*The architectural design of modern buildings has been highly integrated and multi-functional. Connected high-rise structures, which comprise of main towers and corridor in between at a certain height falls under the category of irregular building structure system. This thesis presents a study on the various buildings with connecting structures, under lateral loading conditions such as the seismic loads. The software ETABS was used for modeling the structure. Linear static analysis and linear dynamic analysis was conducted to analyse the models. For seismic loading, the parameters such as storey displacements, storey drifts, overturning moment, base shear, axial and bending moments in the corridor beams are studied. It is understood that each building behaved differently under seismic loads*.

***Keywords*—base shear, connected corridors, drift, overturning moment seismic analysis.**

## I. INTRODUCTION

Earthquakes has always been a major hazard to human beings as well as structures which serve humans important facilities. Seismic analysis is the branch of structural analysis which calculates the response of structures to earthquakes. Double tower connected building is a kind of complicated structure form with two single towers as major structure which are connected by linkwork such as corridors. The connecting body is provided at a certain height and forms an irregular building structural system. More and more connected structures with long- span corridors have been constructed during the years.

The connection provide convenience for communication among different towers and is an important means of escape when one tower suffers calamities like fire. Static performance of high rise connected structure is simple and mature. Location of connection will change the dynamic characteristics of tall buildings and can also change the response caused by earth quake, wind or other loads. The behaviour of the structure as well as the members of the corridor depends on the type of connection used for the corridor.

## II. OBJECTIVES

The objective has been formulated based on gaps that have been faced in study related to connected structures. The objectives of this study include the study on the behaviour of twin buildings with connecting corridor under dynamic loading and its behaviour with changes of connecting beam location with varying span.

## III. MODELLING OF THE STRUCTURE

The building used for the study is a reinforced concrete ten storied twin tower with connecting corridors at different storey levels and with varying spans of corridors. Both in the transverse and longitudinal directions the model has 3 bays with each bay having 8m as centre to centre distance. The story height is 3 m for all storeys. The base nodes of all columns are restrained against translation and rotation about all the 3 global axes. The properties of various frame member sections are listed in table 1.

**TABLE 1**
**MEMBER SPECIFICATIONS**

| Member type | Dimension | Material property |
|---|---|---|
| Column | 650 mm x 650 mm | $M_{30}$& $Fe_{415}$ |
| Beam | 300 mm x 800 mm | $M_{25}$& $Fe_{415}$ |
| Slab | 120 mm thick | $M_{25}$& $Fe_{415}$ |
| Shear wall | 200 mm thick | $M_{30}$& $Fe_{415}$ |

**TABLE 2**
**MODELS USED FOR STUDY**

| Sl No | Model | Configuration |
|---|---|---|
| 1 | Model 1 | Corridor connected on second storey with 4m span |
| 2 | Model 2 | Corridor connected on second storey with 6m span |
| 3 | Model 3 | Corridor connected on second storey with 8m span |
| 4 | Model 4 | Corridor connected on fifth storey with 4m span |
| 5 | Model 5 | Corridor connected on fifth storey with 6m span |
| 6 | Model 6 | Corridor connected on fifth storey with 8m span |
| 7 | Model 7 | Corridor connected on tenth storey with 4m span |
| 8 | Model 8 | Corridor connected on tenth storey with 6m span |
| 9 | Model 9 | Corridor connected on tenth storey with 8m span |

## IV. STRUCTURAL MODELLING IN ETABS

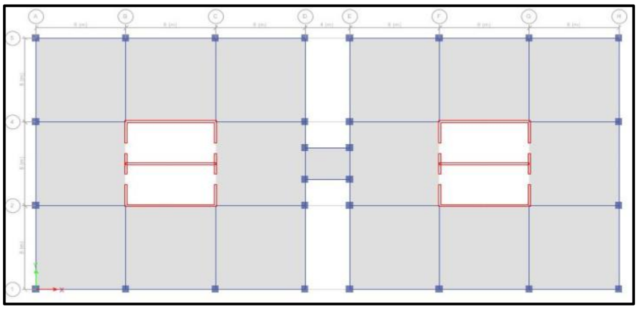

**FIG 1: PLAN VIEW OF THE BUILDING WITH 4m SPAN CONNECTING CORRIDOR**

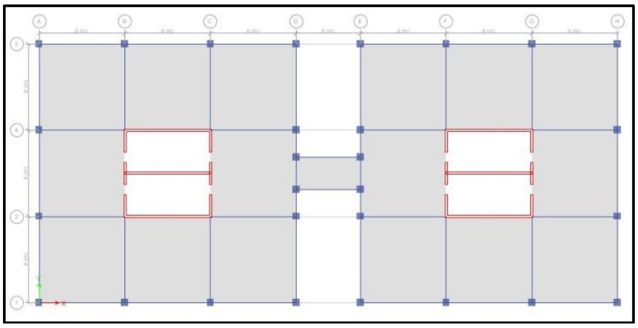

**FIG 2: PLAN VIEW OF THE BUILDING WITH 6m SPAN CONNECTING CORRIDOR**

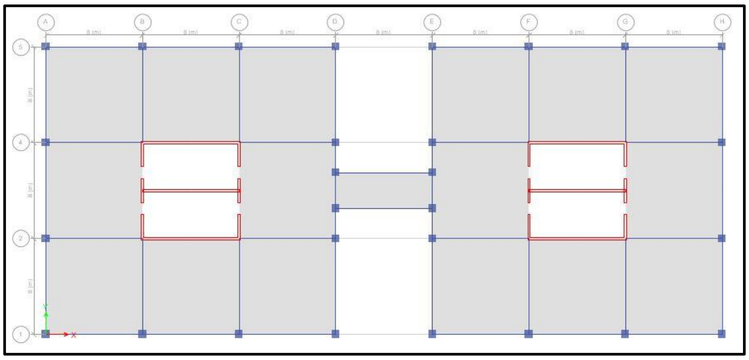

**FIG 3: PLAN VIEW OF THE BUILDING WITH 8m SPAN CONNECTING CORRIDOR**

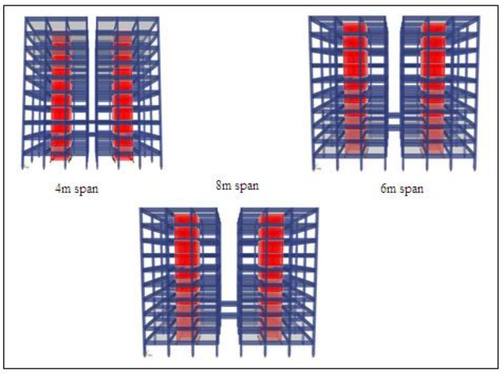


**FIG 4: 3D RENDERED VIEW OF MODEL WITH CORRIDOR CONNECTION AT 2nd storey**

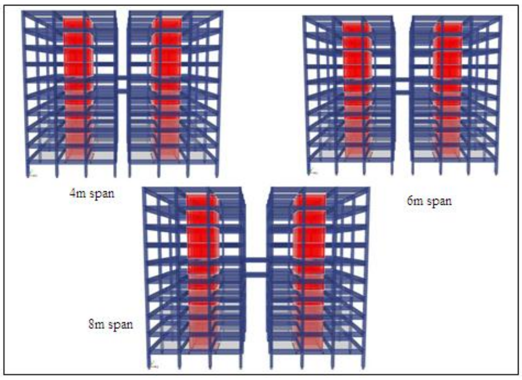


**FIG 5: 3D RENDERED VIEW OF MODEL WITH CORRIDOR CONNECTION AT 5th storey**

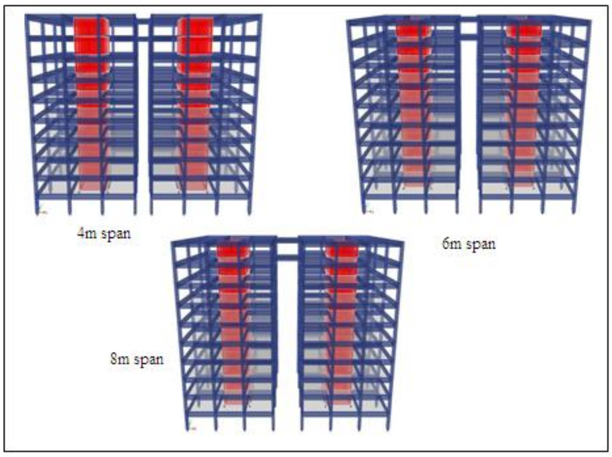


**FIG 6: 3D RENDERED VIEW OF MODEL WITH CORRIDOR CONNECTION AT 10$^{th}$storey**

**TABLE 3**
**LOAD DETAILS**

| Gravity loads | Wind load | Earthquake load |
|---|---|---|
| Dead Load ( beams and columns) = ETABS calculated | $V_b$ = 39m/s | Zone = III (0.16) |
| Self weight of slab = 3kN/m$^2$ | Risk coefficients, k1 = 1 | Importance factor = 1 |
| Floor finish = 1kN/m$^2$ | Topography factor, k3 =1 | Site is hard/rocky site (Type I) |
| Frame loads = 12kN/m | Terrain category = 2 | Response reduction factor taken = 5 |
| Live load (except corridor) = 2kN/m$^2$ | Structure class = B | The seismic load calculations are done by the program by default. |
| Live load (corridor) = 3kN/m$^2$ | $C_p$ (windward) = 0.8 ,$C_p$ (leeward) = 0.5 | |

## V. STRUCTURAL ANALYSIS

The structural analysis is a mathematical algorithm process by which the response of a structure to specified loads and actions is determined.

### 5.1 Linear Dynamic Analysis

Linear Dynamic Analysis can be either the Modal Response Spectrum Method or the Numerical Integration Linear Time History Method using a structural model but in both cases, the corresponding internal forces and displacements are determined using linear elastic analysis. The ground motion histories used in the Numerical Integration Linear Time History Method shall be compatible with a response spectrum constructed from the design spectral acceleration values. The advantage of these linear dynamic procedures with respect to linear static procedures is that higher modes can be considered.

### 5.2 Response-spectrum analysis

Response-spectrum analysis (RSA) is a linear-dynamic statistical analysis method which measures the contribution from each natural mode of vibration to indicate the likely maximum seismic response of an essentially elastic structure. Response-spectrum analysis provides insight into dynamic behavior by measuring pseudo-spectral acceleration, velocity, or displacement as a function of structural period for a given time history and level of damping. It is practical to envelope response spectra such that a smooth curve represents the peak response for each realization of structural period.

## VI. RESULTS AND DISCUSSIONS

### 6.1 Storey Displacement

The maximum displacement is determined after the analysis for 9 models. The curve shows storey displacement graphs for different cases studied.

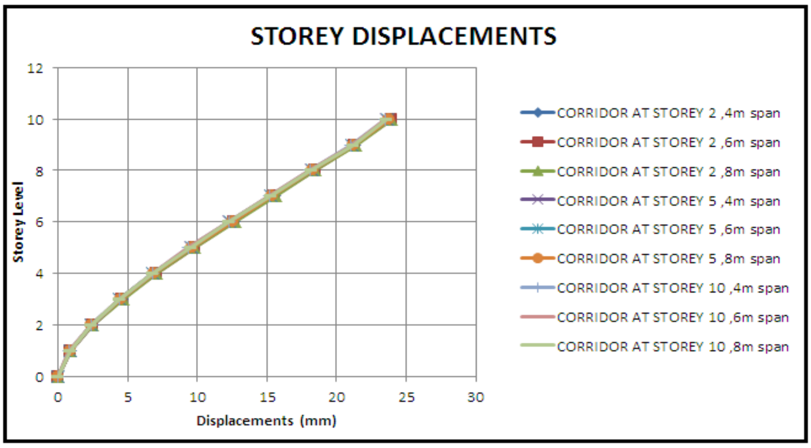


**FIG 7: STOREY DISPLACEMENTS ALONG X DIRECTION**

**TABLE 4**
**STOREY DISPLACEMENTS ALONG X DIRECTION**

| STOREY | CORRIDOR AT STOREY 2 | | | CORRIDOR AT STOREY 5 | | | CORRIDOR AT STOREY 10 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4m span | 6m span | 8m span | 4m span | 6m span | 8m span | 4m span | 6m span | 8m span |
| 10 | 23.8 | 23.9 | 23.9 | 23.6 | 23.7 | 23.8 | 23.5 | 23.5 | 23.6 |
| 9 | 21.3 | 21.3 | 21.4 | 21.1 | 21.1 | 21.2 | 21 | 21.1 | 21.2 |
| 8 | 18.4 | 18.5 | 18.5 | 18.2 | 18.3 | 18.3 | 18.1 | 18.1 | 18.2 |
| 7 | 15.5 | 15.5 | 15.6 | 15.3 | 15.3 | 15.4 | 15.2 | 15.2 | 15.3 |
| 6 | 12.6 | 12.6 | 12.7 | 12.3 | 12.4 | 12.5 | 12.3 | 12.3 | 12.3 |
| 5 | 9.7 | 9.8 | 9.8 | 9.5 | 9.6 | 9.6 | 9.4 | 9.4 | 9.5 |
| 4 | 7 | 7.1 | 7.1 | 6.8 | 6.8 | 6.9 | 6.8 | 6.8 | 6.8 |
| 3 | 4.6 | 4.6 | 4.7 | 4.4 | 4.4 | 4.5 | 4.4 | 4.4 | 4.4 |
| 2 | 2.5 | 2.5 | 2.5 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 |
| 1 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.8 | 0.8 | 0.9 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

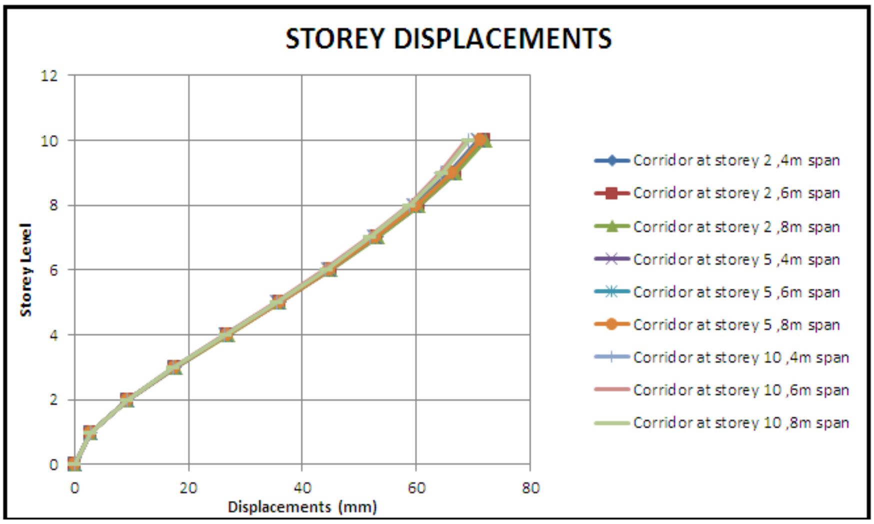


**FIG 8: STOREY DISPLACEMENTS ALONG Y DIRECTION**

**TABLE 5**
**STOREY DISPLACEMENTS ALONG Y DIRECTION**

| Storey | Corridor at storey 2 | | | Corridor at storey 5 | | | Corridor at storey 10 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4m | 6m | 8m | 4m | 6m | 8m | 4m | 6m | 8m |
| 10 | 71.9 | 72 | 72.1 | 70.8 | 71.1 | 71.2 | 69.1 | 68.8 | 69.1 |
| 9 | 66.6 | 66.8 | 66.9 | 65.7 | 66 | 66.1 | 64.4 | 64.2 | 64.6 |
| 8 | 60.3 | 60.4 | 60.5 | 59.6 | 59.8 | 59.9 | 58.7 | 58.5 | 58.9 |
| 7 | 53 | 53.1 | 53.2 | 52.5 | 52.7 | 52.8 | 51.9 | 51.7 | 52 |
| 6 | 44.8 | 44.9 | 45 | 44.5 | 44.7 | 44.8 | 44.1 | 43.9 | 44.2 |
| 5 | 36 | 36 | 36.1 | 35.6 | 35.8 | 35.9 | 35.5 | 35.3 | 35.6 |
| 4 | 26.7 | 26.8 | 26.9 | 26.5 | 26.6 | 26.7 | 26.4 | 26.3 | 26.5 |
| 3 | 17.6 | 17.6 | 17.7 | 17.5 | 17.6 | 17.6 | 17.4 | 17.3 | 17.4 |
| 2 | 9.2 | 9.2 | 9.3 | 9.3 | 9.3 | 9.3 | 9.2 | 9.2 | 9.2 |
| 1 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

It is seen that the maximum displacement occurs for buildings with corridor at storey 2. The displacement is independent of the span of corridor and shows variation when the level of connection change. The displacement is maximum along the Y direction.

### 6.2 Storey Drift

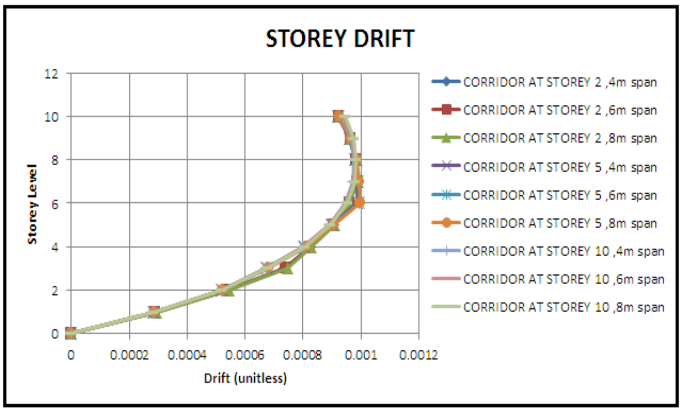


**FIG 9: STOREY DRIFT ALONG X DIRECTION**

**TABLE 6**
**STOREY DRIFT ALONG X DIRECTION**

| STOREY | CORRIDOR AT STOREY 2 | | | CORRIDOR AT STOREY 5 | | | CORRIDOR AT STOREY 10 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4m span | 6m span | 8m span | 4m span | 6m span | 8m span | 4m span | 6m span | 8m span |
| 10 | 0.000923 | 0.000923 | 0.000924 | 0.00092 | 0.000922 | 0.000925 | 0.00094 | 0.000942 | 0.000946 |
| 9 | 0.000963 | 0.000964 | 0.000966 | 0.000959 | 0.000962 | 0.000965 | 0.000969 | 0.000972 | 0.000977 |
| 8 | 0.000983 | 0.000984 | 0.000986 | 0.00098 | 0.000983 | 0.000986 | 0.000976 | 0.000978 | 0.000983 |
| 7 | 0.000983 | 0.000985 | 0.000987 | 0.000986 | 0.000989 | 0.000993 | 0.000973 | 0.000975 | 0.00098 |
| 6 | 0.000958 | 0.00096 | 0.000962 | 0.000987 | 0.000993 | 0.000998 | 0.000946 | 0.000948 | 0.000953 |
| 5 | 0.000904 | 0.000906 | 0.000908 | 0.000899 | 0.000903 | 0.000907 | 0.00089 | 0.000891 | 0.000895 |
| 4 | 0.000823 | 0.000825 | 0.000828 | 0.000802 | 0.000806 | 0.000809 | 0.000799 | 0.0008 | 0.000804 |
| 3 | 0.000737 | 0.000741 | 0.000746 | 0.000674 | 0.000677 | 0.00068 | 0.000672 | 0.000673 | 0.000676 |
| 2 | 0.000537 | 0.00054 | 0.000543 | 0.000519 | 0.000521 | 0.000523 | 0.000517 | 0.000517 | 0.000519 |
| 1 | 0.00029 | 0.000291 | 0.000293 | 0.000284 | 0.000285 | 0.000286 | 0.000283 | 0.000283 | 0.000284 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

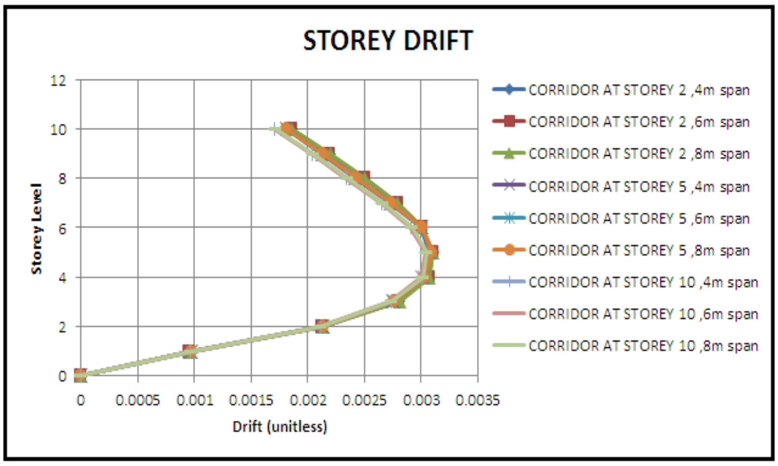


**FIG 10: STOREY DRIFT ALONG Y DIRECTION**

**TABLE 7**
**STOREY DRIFT ALONG Y DIRECTION**

| STOREY | CORRIDOR AT STOREY 2 | | | CORRIDOR AT STOREY 5 | | | CORRIDOR AT STOREY 10 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4m span | 6m span | 8m span | 4m span | 6m span | 8m span | 4m span | 6m span | 8m span |
| 10 | 0.001857 | 0.001858 | 0.00186 | 0.00181 | 0.001811 | 0.001811 | 0.001709 | 0.001707 | 0.001715 |
| 9 | 0.002192 | 0.002194 | 0.002198 | 0.002129 | 0.002134 | 0.002135 | 0.002042 | 0.002038 | 0.002045 |
| 8 | 0.002498 | 0.002501 | 0.002505 | 0.002418 | 0.002424 | 0.002426 | 0.00234 | 0.002334 | 0.002348 |
| 7 | 0.002785 | 0.002788 | 0.002792 | 0.002727 | 0.002735 | 0.002738 | 0.002654 | 0.002648 | 0.002664 |
| 6 | 0.002998 | 0.003002 | 0.003006 | 0.002993 | 0.003003 | 0.003009 | 0.002906 | 0.002898 | 0.002915 |
| 5 | 0.003098 | 0.003102 | 0.003106 | 0.003069 | 0.003081 | 0.003087 | 0.003043 | 0.003033 | 0.003052 |
| 4 | 0.00306 | 0.003065 | 0.00307 | 0.003011 | 0.003024 | 0.00303 | 0.003011 | 0.003 | 0.003018 |
| 3 | 0.002798 | 0.002805 | 0.00281 | 0.002743 | 0.002755 | 0.002761 | 0.002735 | 0.002722 | 0.002739 |
| 2 | 0.002119 | 0.002127 | 0.002131 | 0.002124 | 0.002134 | 0.002139 | 0.002109 | 0.002099 | 0.002113 |
| 1 | 0.000952 | 0.000956 | 0.000958 | 0.000969 | 0.000974 | 0.000977 | 0.000961 | 0.000956 | 0.000963 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Along both the directions, the storey drift shows a smooth curve and shows a small variation along the span of corridor and the level of connection.

### 6.3 Overturning Moment

Response to earthquake ground motion results in a tendency for structures and individual vertical elements of structures to overturn about their bases. Although actual overturning failure is very rare, overturning effects can result in significant stresses. The overturning moment at the base for different locations and for different spans of corridors are compared below.

**TABLE 8**
**OVERTURNING MOMENT AT THE BASE ALONG X DIRECTION**

| | Corridor at Storey 2 | | | Corridor at Storey 5 | | | Corridor at Storey 10 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4m | 6m | 8m | 4m | 6m | 8m | 4m | 6m | 8m |
| X | 256866.4 | 256908.3 | 257145.8 | 260032.5 | 260170 | 260705.8 | 255651.4 | 255816.6 | 255979.1 |
| Y | 409298.3 | 409481 | 409853 | 410716.2 | 411253.2 | 411581.3 | 411910.6 | 412030.4 | 413668.1 |

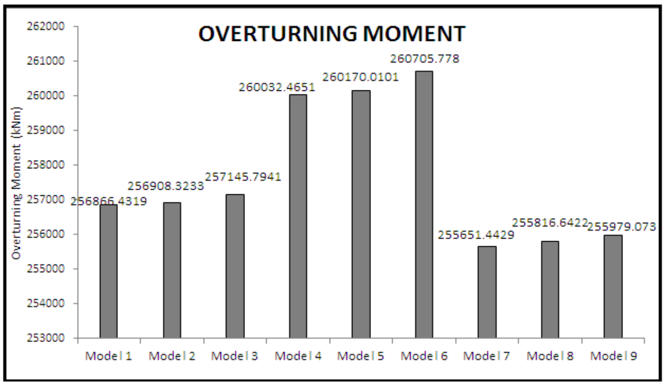


**FIG 11: OVERTURNING MOMENT AT THE BASE ALONG X DIRECTION**

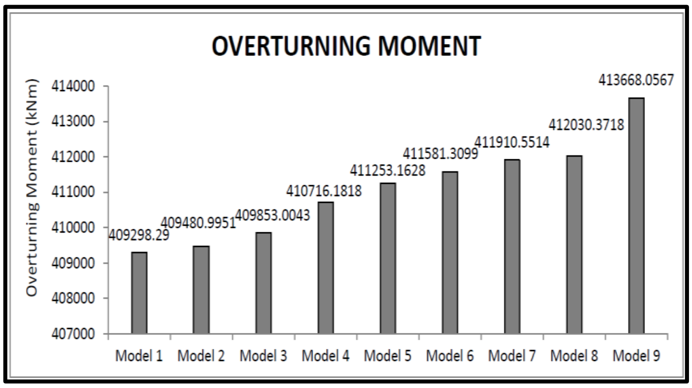


**FIG 12: OVERTURNING MOMENT AT THE BASE ALONG Y DIRECTION**

It is observed that the building experiences lesser overturning moment when the corridor location is at storey 2 with 4m span. The overturning moment is observed higher when the corridor is at storey 10 with 8m span. There is an increasing variation of overturning moment when corridor location increases to the top and with increasing span.

### 6.4 Base Shear

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure.

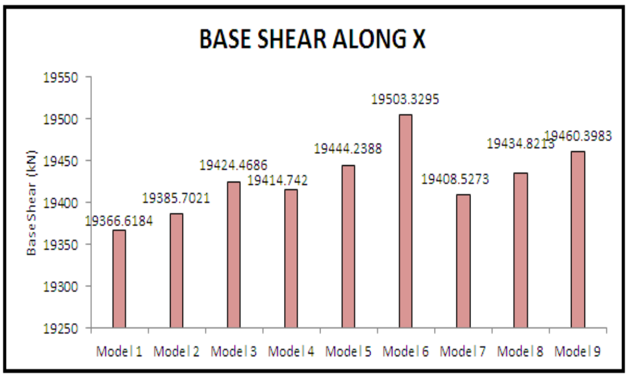


**FIG 13: BASE SHEAR ALONG X DIRECTION**

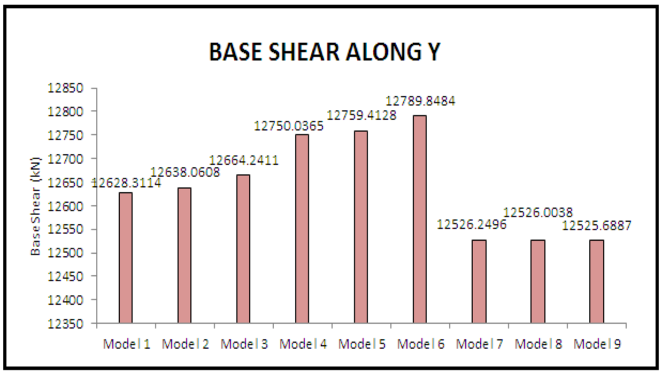


**FIG 14: BASE SHEAR ALONG Y DIRECTION**

**TABLE 9**
**BASE SHEAR ALONG X AND Y DIRECTION**

| Span | Corridor at storey 2 | | | Corridor at storey 5 | | | Corridor at storey 10 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4m | 6m | 8m | 4m | 6m | 8m | 4m | 6m | 8m |
| Base shear along X | 19366.62 | 19385.7 | 19424.47 | 19414.74 | 19444.24 | 19503.33 | 19408.53 | 19434.82 | 19460.4 |
| Base shear along Y | 12628.31 | 12638.06 | 12664.24 | 12750.04 | 12759.41 | 12789.85 | 12526.25 | 12526 | 12525.69 |

The maximum base shear is seen along the X direction. The maximum shear occurred in model 6 in which the corridor is located at the midspan ($5^{th}$storey) with 8m span. The minimum occurred in model 1 where corridor is at $2^{nd}$storey with 4m span.

### 6.5 Axial force in the connecting beams

The variation of axial force in the connecting beam of the corridor are plotted both for the beams at the top and bottom section.

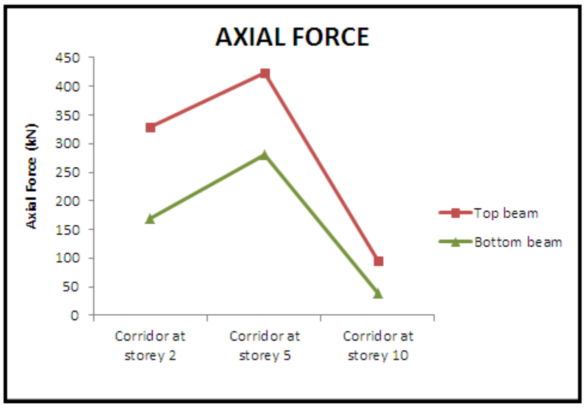


**FIG 15: AXIAL FORCE VARIATION FOR SPAN 4m**

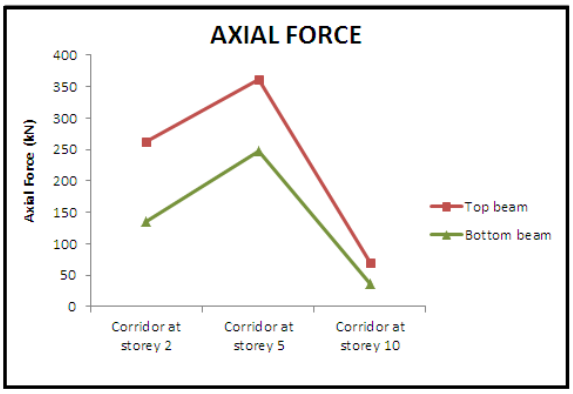


**FIG 16: AXIAL FORCE VARIATION FOR SPAN 6m**

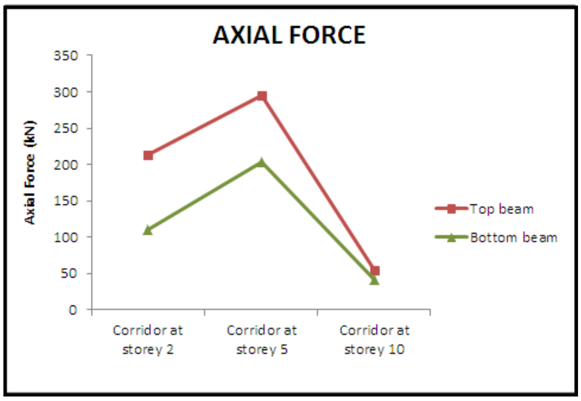


**FIG 17: AXIAL FORCE VARIATION FOR SPAN 8m**

**TABLE 10**
**AXIAL FORCE IN THE CONNECTING BEAMS OF CORRIDOR**

| | Corridor at storey 2 | | | Corridor at storey 5 | | | Corridor at storey 10 | | |
|---|---|---|---|---|---|---|---|---|---|
| Span | 4m | 6m | 8m | 4m | 6m | 8m | 4m | 6m | 8m |
| Top beam | 329.8088 | 261.5162 | 213.134 | 424.2818 | 362.1466 | 295.3945 | 95.9864 | 69.5933 | 55.2068 |
| Bottom beam | 169.1094 | 136.1904 | 110.9416 | 279.7786 | 247.0731 | 203.8297 | 38.1974 | 36.0298 | 31.3848 |

From the table 10, it is seen that the axial force developed in the beams increases to the to the mid-span and then decreases when the location of connecting beams shifts to the top storey. Maximum axial force is developed when the corridor is connected at the mid-span with 4m span and minimum axial force is when the corridor is located at the top storey.

### 6.6 Bending moment in the connecting beams

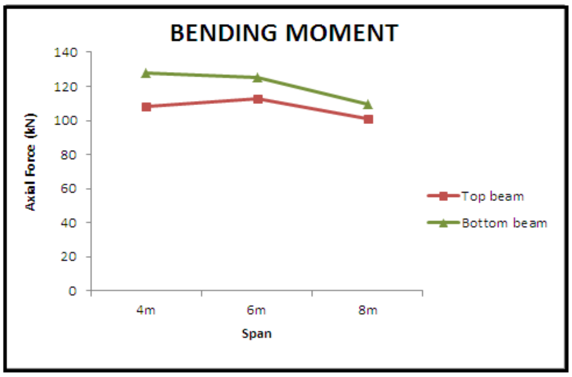


**FIG 18: BENDING MOMENT VARIATION FOR CORRIDOR AT STOREY 2**

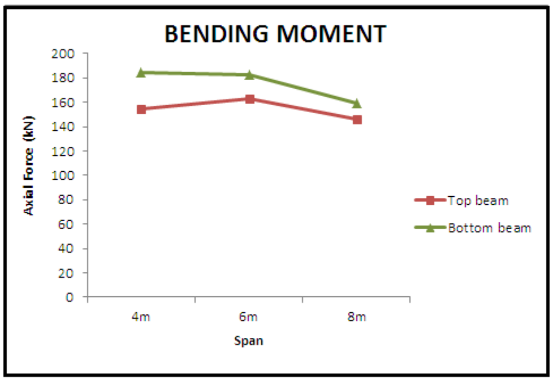


**FIG 19: BENDING MOMENT VARIATION FOR CORRIDOR AT STOREY 5**

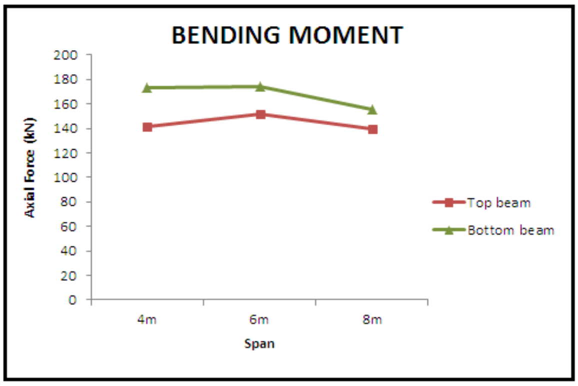


**FIG 20: BENDING MOMENT VARIATION FOR CORRIDOR AT STOREY 10**

**TABLE 11**
**BENDING MOMENTS IN THE CORRIDOR BEAMS**

| Span | Corridor at storey 2 | | | Corridor at storey 5 | | | Corridor at storey 10 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4m | 6m | 8m | 4m | 6m | 8m | 4m | 6m | 8m |
| **Top beam** | 108.2642 | 112.7959 | 101.2085 | 154.9681 | 162.8562 | 146.0776 | 141.68 | 151.8728 | 139.717 |
| **Bottom beam** | 127.6075 | 125.1119 | 109.5206 | 184.5692 | 182.2704 | 159.2228 | 173.5324 | 174.0001 | 155.2175 |

The bending moments increases from 4m span to 6m span models and then decreases in 8m span models for top beams. As the location of the corridor changes bending moment increases and maximum obtained when the corridor is at the midspan. In the case of bottom beams bending moment shows a decreasing tendency with span.

### 6.7 Discussion

The discussion of the results obtained for the models can be explained by taking into consideration each parameter.

- **Storey displacement and Storey drift**

The storey displacements and storey drifts for seismic loading are found. Maximum displacement occurred along the Y direction and is seen in models where the corridor is connected at the second storey. The maximum displacement depends on the span of the corridor and is less varied with changing location of corridors. The minimum displacement is obtained when the corridor is located on the tenth storey. The storey drift is maximum along the Y direction. A sudden variation in drift is seen after the location of corridors in case of wind loading along the X direction.

- **Overturning Moment**

The overturning moment is seen maximum when the corridor is connected at the tenth storey with maximum span. The least value of overturning moment is observed for models with corridors at storey 2. The overturning moment increased with increasing altitude of connection of corridor and with increasing span.

- **Base Shear**

The maximum base shear is seen along the X direction. The maximum base shear is seen when the corridor location is at mid-span of the structure.

- **Axial Force and Bending Moments**

The axial force and bending moment developed in the corridor beams is maximum when they are located to the midspan of the structure. As the location of beams shifts to the top storey the axial force gets decreased. As the location of the corridor changes bending moment increases. In the case of beams at the bottom bending moment shows a decreasing tendency with span.

## VII. CONCLUSION

Compared with the ordinary buildings, the characteristics of connected buildings are complex and changes with the connection location. These high and flexible structures have large movements under lateral forces like earthquakes and winds. The effort of the connecting corridor location changes the structure behaviour in terms of displacement, drift, overturning moment, base shear, axial force and bending moments. The results indicate that the horizontal displacement and drift under seismic loading in Y direction is larger than the displacements and drifts in X direction. Overturning moment depends on location and span of the corridors. The effort to maximum base shear is larger in X direction than Y direction. The above results provide references for design and for further study.

## VIII. SCOPE OF FUTURE WORK

This research and investigation has opened a vast scenario for future studies. In this subject, extensive explorations can be conducted with a wide range of variation in connecting corridors and building characteristics.

Further studies may be carried out by adding the following variations to the research prototypes;

- Variation in span of the connecting corridors.
- Incorporating multiple corridors within the structure.
- Steel connections for the corridor.
- Corridors between varying altitude towers.
- Changing the type of connection of corridor to the structure.

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