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Study on Mass Lumping Methods of Framed Structures

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***Abstract*—Usually the seismic weight (W) is found out by lumping the total mass of the structure at the beam column junctions in a building. Lumping of mass in a RC framed structure can be achieved using different techniques. This paper does a comparison of different techniques used to lump the masses in a structure, along with the response of each method on the behavior of a multistoreyed building. The accuracy of the methods is finalized by comparing the analysis results with a building analysed using time history method. Finite Element package SAP 2000 V14.0.0 is used for the study.**

Keywords- Seismic weight, Time history method, multistoried building, SAP 2000, mass lumping.

I. INTRODUCTION

Earthquake shaking is the most severe among all loads like wind loads, wave loads, blast loads, snow loads, imposed loads and dead loads. Because it imposes time varying displacement under the building. As a result the building undergoes lateral deformation between its base and upper elevations. Severity of this imposed relative deformation is larger in higher seismic zones. The building should withstand this deformation with damage under small intensity shaking and with no collapse under high intensity shaking. To sustain the forces and moments induced in them, the building must possess large inelastic deformation capacity and have the strength in all its structural components. A design engineer plays an important role in maintaining structural safety of the building by employing suitable procedures in the seismic design. Mass lumping is therefore an important step in the analysis of an earthquake resistant building to impose horizontal deformations. Mass lumping is a numerical technique related to the finite element method (FEM) that has been widely used in different applications such as to determine the seismic weight of buildings, transport problems, heat transfer problems etc. In other words it is a method of discretization in which the distributed mass of the elements is lumped at the nodes or joints. This paper shows the effect of different mass lumping methods on floor displacement of a G+12 residential multistoried structure. The mass lumping methods considered are joint weight method, element weight method, member weight method, floor weight method and self weight factor method.

II. SCOPE & OBJECTIVE

A. *Scope of the study*

- Analysis of multi-storeyed RC framed structures is a tedious and time consuming task, determination of apt mass lumping technique is very useful for a structural engineer for calculating seismic behavior of the structure.

B. *Objectives of the Study*

- To analyze a multi-storeyed RC building, by using different methods such as equivalent static analysis, response spectrum analysis and time history analysis.
- To study the effect of mass lumping methods on floor displacements for each method of analysis.
- To suggest the most suitable method for mass lumping.
- To study the effect of variation in height of the building on floor displacement values for all the above methods of mass lumping and analysis.
- To study the effect of lumping the masses on a member with intermediate nodes by comparing it with conventional technique.

III. METHODOLOGY

- Modelling of RC framed structure: Fixing the dimensions, support conditions, assigning properties and loads.
- Application of mass lumping methods: Different mass lumping methods were applied to the modelled structure.
- Analysis the model: The model was analysed using various methods of structural analysis such as Equivalent static method, Response spectrum method and Time History method.
- Analysis of results: The results were analysed to get the response of each method and has to be arrived at a conclusion that the method that gives maximum floor displacement should be the most effective method of mass lumping.

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IV. SEISMIC ANALYSIS

Seismic analysis is a subset of structural analysis and is the calculation of the response of a building structure to earthquakes. Various methods of different complexity have been developed for the seismic analysis of structures.They can be classified as follows.

1. Equivalent Static Analysis
2. Non Linear Static Analysis
3. Response Spectrum Analysis
4. Non Linear Dynamic Analysis

1. *Equivalent Static Analysis*

This approach defines a series of forces acting on a building to represent the effect of earthquake ground motion. It assumes that the building responds in its fundamental mode. For this to be true, the building must be low-rise and must not twist significantly when the ground moves. The response is read from a design response spectrum, given the natural frequency of the building. The applicability of this method is extended in many building codes by applying factors to account for higher buildings with some higher modes, and for low levels of twisting. To account for effects due to yielding of the structure, many codes apply modification factors that reduce the design forces.

2. *Nonlinear Static Pushover Analysis*

In general, linear procedures are applicable when the structure is expected to remain nearly elastic for the level of ground motion or when the design results in nearly uniform distribution of nonlinear response throughout the structure. As the performance objective of the structure implies greater inelastic demands, the uncertainty with linear procedures increases to a point that requires a high level of conservatism in demand assumptions and acceptability criteria to avoid unintended performance. Therefore, procedures incorporating inelastic analysis can reduce the uncertainty and conservatism. This approach is also known as pushover analysis. A pattern of forces is applied to a structural model that includes non-linear properties and the total force is plotted against a reference displacement to define a capacity curve. This can then be combined with a demand curve. This essentially reduces the problem to a single degree of freedom (SDOF) system. Nonlinear static procedures use equivalent SDOF structural models and represent seismic ground motion with response spectra. Story drifts and component actions are related subsequently to the global demand parameter by the pushover or capacity curves that are the basis of the non-linear static procedures

3. *Linear Dynamic Response Spectrum Method*

This approach permits the multiple modes of response of a building to be taken into account. This is required in many building codes for all except very simple or very complex structures. The response of a structure can be defined as a combination of many special shapes (modes) that in a vibrating string correspond to the harmonics. Computer analysis can be used to determine these modes for a structure. For each mode, a response is read from the design spectrum, based on the modal frequency and the modal mass, and they are then combined to provide an estimate of the total response of the structure. In this we have to calculate the magnitude of forces in all directions i.e. X, Y & Z and then see the effects on the building The result of a response spectrum analysis using the response spectrum from a ground motion is typically different from that which would be calculated directly from a linear dynamic analysis using that ground motion directly, since phase information is lost in the process of generating the response spectrum. In cases where structures are either too irregular, too tall or of significance to a community in disaster response, the response spectrum approach is no longer appropriate, and more complex analysis is often required, such as non-linear static analysis or dynamic analysis.

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4. *Non-linear Dynamic Time-History Analysis*

Nonlinear dynamic analysis utilizes the combination of ground motion records with a detailed structural model, therefore is capable of producing results with relatively low uncertainty. In nonlinear dynamic analyses, the detailed structural model subjected to a ground-motion record produces estimates of component deformations for each degree of freedom in the model and the modal responses are combined using schemes such as the square-root-sum-of-squares. In non-linear dynamic analysis, the non-linear properties of the structure are considered as part of a time domain analysis. This approach is the most rigorous, and is required by some building codes for buildings of unusual configuration or of special importance. However, the calculated response can be very sensitive to the characteristics of the individual ground motion used as seismic input; therefore, several analyses are required using different ground motion records to achieve a reliable estimation of the probabilistic distribution of structural response. Since the properties of the seismic response depend on the intensity, or severity, of the seismic shaking, a comprehensive assessment calls for numerous nonlinear dynamic analyses at various levels of intensity to represent different possible earthquake scenarios.

V. STRUCTURAL MODELLING

The model considered for the study is G+12 RCC multistoreyed building**.** Building is modelled for Indian seismic zone III IS: 1893-2002. Plan dimension in X and Y and Z direction is 32.29 m, 39 m and 15.78 m respectively.
The buildings has following dimensions,
Columns size - 300mm x700mm
All beam size - 200mm x 600mm.
Floor slabs are taken as 150 mm thick.
The height of all floors is 3m.
5% Modal damping is considered.
Soil type is medium.
M25 grade concrete and Fe415 steel is used.

Loads Assigned

For given structure dead load, live load and earthquake load are applied according to IS 875 part I, Part II and IS 1893:2002 respectively.

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a. Live load

Live load on Staircase - 3 kN/m^2
Live load on roof – 0.75 kN/m^2
Live load on all other floors - 3 kN/m^2

b. Dead Load

Wall load = (unit weight of brickwork) x (thickness of wall) x (height of wall).
Unit weight of brickwork = 20 kN/m^3
Thickness of wall = 0.23 m

Wall load on roof level =20 x 0.23 x 1=4.60 kN/m
Wall load on all other levels =20 x 0.23x3 = 13.6kN/m

c. Load Combinations

All the required load combinations as per IS 456:2000 and IS 1893 (part 1):2002 for static and dynamic analysis were applied to the modelled structures. The load combinations applied ensures adequate strength and serviceability to the structures.

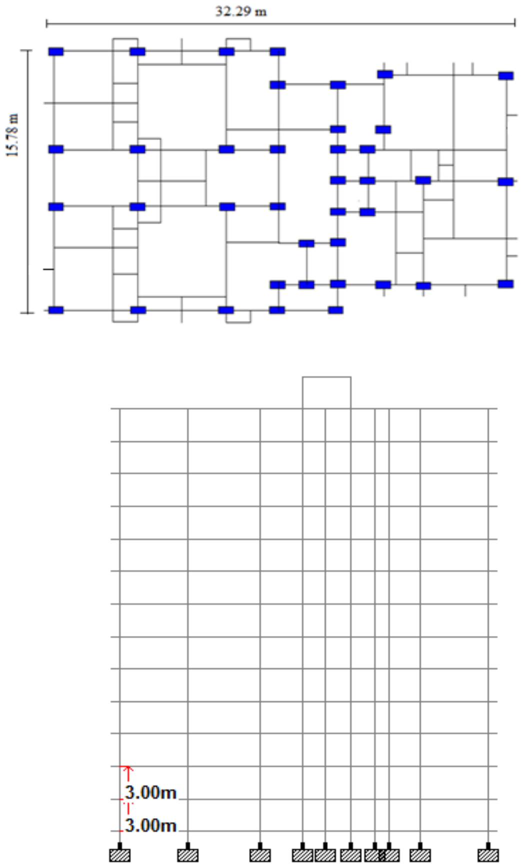

Fig.1 Plan and Elevation of G+12 RCC Multistoreyed Building

VI. METHODS OF MASS LUMPING

The different methods used to lump the masses includes

1. Self weight Factor Method
2. Joint Weight Method
3. Member Weight Method
4. Element Weight Method
5. Floor Weight Method

1. Self weight Factor Method

In this method of mass lumping, the whole mass of the structure is considered to be distributed along the full structure. This is done by multiplying the self weight of the building with a factor, usually 1.

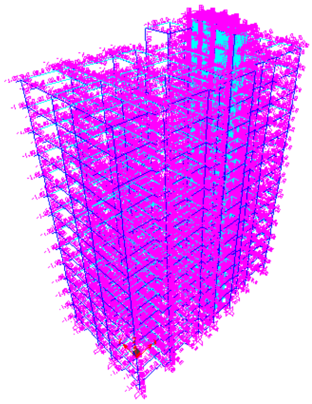

Fig 2 Structure Subjected to self weight

2. Joint Weight Method

In this method, we apply the joint weight which corresponds to the respective nodal load applied on the structure. For joint weight calculation, a pin support is introduced at all the beam-column junction of the structure. Then create a seismic load combination case, taking in consideration all the dead load and live load factors. Then the analysis is performed and the FY (vertical reaction) values at all the pinned support for load combination is taken. This FY value is the lumped mass or the joint weight at the particular node/joint. It is the amount of lumped weight at the joint and will contribute towards the total base shear for the structure.

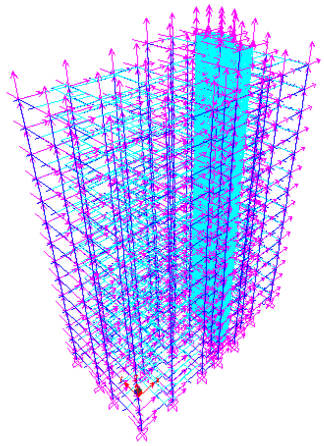

Fig 3 Structure Subjected to Joint Weight

3. Member Weight Method

In this method, we assume that mass of the structure is concentrated at the horizontal members i.e.; the beams. The dead load of the slab, brick load and the live loads are applied as uniformly distributed loads on the beams. The structure is then analyzed for these loads and the corresponding responses are noted.

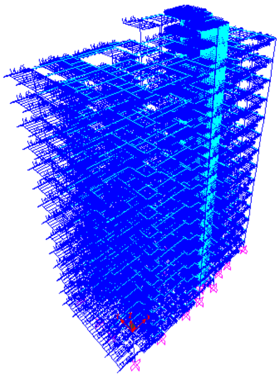

Fig 4 Structure Subjected to Member Weight

4. *Element Weight Method*

In Element Weight method, slabs are considered. Plates are drawn on each floor corresponding to slabs of each floor. The plates are given the same thickness of the slab. Dead load of the slabs, brick load and live load are applied as pressure on these plates. The structure is then analyzed for these plate loads and the responses are noted.

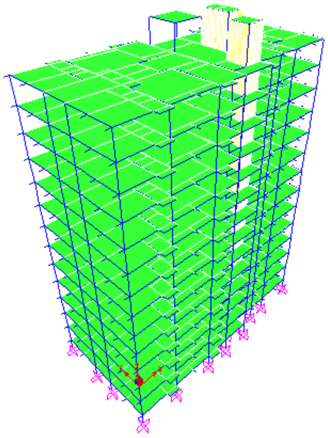

Fig 5 Area Loads Applied on Slab

5. *Floor Weight Method*

This method is similar to Element weight method except for the fact that the buildings are analyzed without slabs. That is brick load; live load and self weight of the slab are applied directly to the floors.

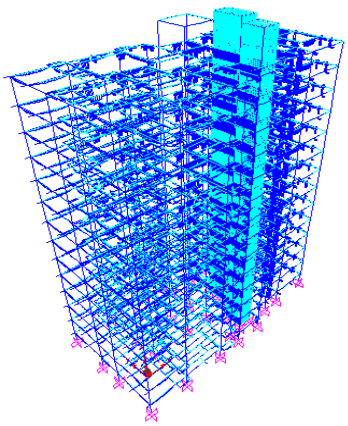

Fig 6 Loads applied on Floor

VII. ANALYSIS OF THE STRUCTURE

Mainly three types of analysis procedures have been carried out for determining the floor displacements of the model. We are mainly concerned with the behavior of the structure under the ground motion and dynamic excitations such as earthquakes and the displacement of the structure in the inelastic range.

The analysis carried out is as follows:

- Equivalent Static Analysis.
- Response Spectrum Analysis.
- Time History Analysis.

Time History Considered for Study:-

For the purpose of earthquake resistant analysis and design of structures, realistic ground motion is required. In most of the cases it may not be possible to have strong motion records at a given site. It is very essential to have specific time history for a specific site. So, a synthetic time history must be derived. Here a synthetic time history is derived assuming that target response spectra is known. The target response spectra adopted is the response spectra for 5% damping as provided in IS 1893(part 1): 2002. The target response spectra are converted to required time history file using special software.

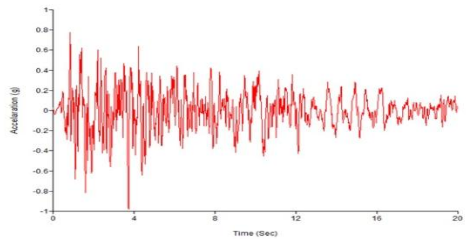

Fig 7 Generated Time History Graph

VIII. RESULTS AND ADISCUSSIONS

Response of G+12 RCC multistoreyed building subjected to different methods of mass lumping were computed. Time History analysis, response spectrum analysis and equivalent static analysis were performed using five methods of mass lumping. SAP 2000 is used to compute the response for time history and response spectrum analysis and STAAD Pro 2007 is used to compute the response for equivalent static analysis. Results from different methods of analysis were used to observe and compare the floor responses of all the models.

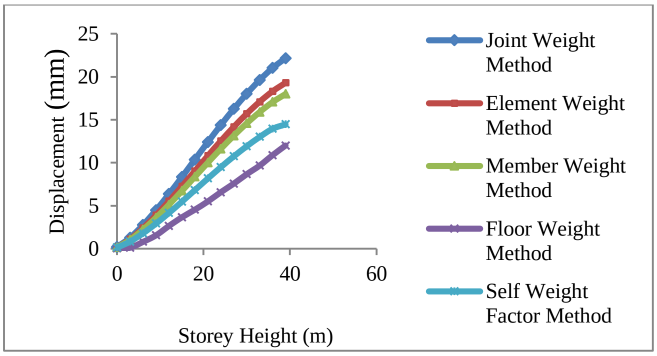

Fig 8 Variation in Floor Displacement Values after Equivalent Static Analysis

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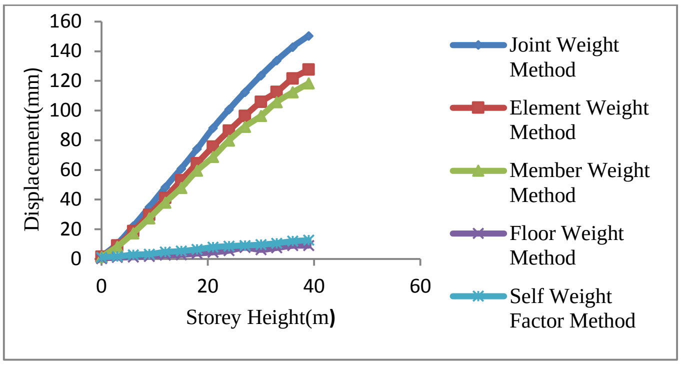

Fig 9 Variation in Floor Displacement Values after Response Spectrum Analysis

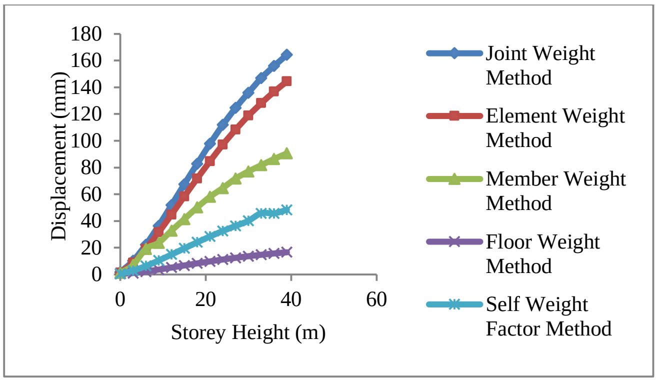

Fig 10 Variation in Floor Displacement Values after Time History Analysis

IX. CONCLUSIONS

- The study aims at comparing various mass lumping methods for determining seismic weight of a building.
- Finite Element software SAP 2000 and STAAD PRO V8i were used for the study.
- The study involved the creation and analysis of the models using time history, response spectra and equivalent static method of analysis.
- The results of the models are compared to study the effects of mass lumping methods on structural displacement of the building.
- From graph of storey displacement it is observed that the displacement obtained by time history analysis is higher than response spectrum and equivalent static analysis.
- From the above illustrations it is clear that joint weight method of mass lumping produces more displacement in the floors compared to other methods.
- This is because in joint weight method mainly the loads are transferred through the column without bypassing the beams.
- Element weight method, member weight method, floor weight method and self weight method follows joint weight method in succession.

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