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Study on Industrial Building with Heavy Machinery under Dynamic Loading using Floor Response Spectrum Method

Muhsina C.K.
M Tech Student,
ICET
Muvattupuzha, India

Jaisal A.K.
Asst. Professor,
ICET
Muvattupuzha, India

Romy Mohan
Structural Engineer,
WVA Consulting Engineers
Kolenchery, India

***Abstract*— The analysis of a multistoried building with heavy machinery under dynamic loading is usually done by response spectrum method. Here the objective is to determine the ideal property of machinery that can be placed at each floor level, where the property of the machinery is defined in terms of natural frequency and weight. To achieve this, different machinery setups are placed at different floors and are analysed when subjected to excitation at corresponding floor levels in the form of floor response spectra. First the study, the response of the building at the floor levels has been generated by excitation at ground level as well as at floor levels, in the form of 'ground response spectra' and 'floor wise response spectra' respectively. Next the response of the machineries of different combination of natural frequency of machinery foundation 1Hz, 3Hz, 5Hz, 7Hz, 10Hz and weights 1000kN, 5000kN, 1000kN has been analysed by placing them at different floor levels in the building with same plan for all floors as well as different plan for different floors.**

Keywords*— machinery placing, Response Spectrum Method, Floor Response Spectrum Method.

I. INTRODUCTION

Industrial buildings are very susceptible to earthquake loading due to the presence of heavy machineries. So the analysis and design of this type of building is very important. Seismic loads and analysis has become of increasing importance in all over the world. This is due to the frequency of large magnitude seismic events that have been witnessed, often in large metropolitan areas, typically resulting in tragic loss of life. As a direct result greater efforts have been made to understand and quantify loads that might be experienced during an earthquake. In industrial building like Nuclear Power Plant all safety related systems are designed to resist and to keep the operatability during and after a postulated earthquake. The diversity and the large number of the secondary systems in an industrial building lead to the response spectra methodology for the seismic analysis of the secondary systems. Floor response spectrum method is used for the analysis of this type of structures.

A. Floor Response Spectrum

When earthquakes occur the ground floor is excited. Base excitation force is developed in the ground floor, as we move on to top floor the load developed is increases. The spectrum developed on each floor is generated. This is known as floor response spectrum.

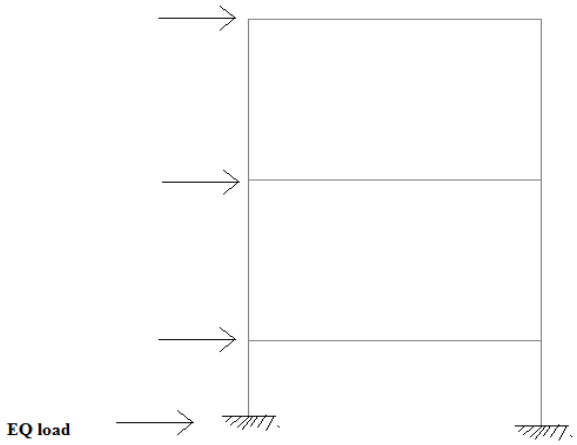

Fig 1.Earthquake load acting on a building

Main objectives of the study are

- To study the response of industrial building with heavy machinery under the effect of dynamic loading.
- To generate the floor wise response spectra and compare the values.
- To analyse each floor by ground floor response spectrum as well as floor wise response spectra and compare the responses.
- To determine the ideal property of the machinery foundation that can be placed for each floor level

II. LITERATURE SURVEY

[1] Subramanian K.V. studied about the nuclear power plant. He concludes that one of the contributors in increasing the cost of an NPP is seismic design. A cost-effective seismic design of NPP is possible, if the seismic design is standardized. This can be achieved by using passive seismic response control devices, such as isolators, elasto-plastic dampers and lead-extrusion dampers. [2] Julien Richard, the response spectrum analysis method provided a fair prediction of both the deformation and force seismic demand. [3] Mathews Wilson concludes that as it is preferable that the structure should be designed with the help of the response data obtained from the spectral analysis which gives scope for a more economical construction of the multistoried building.

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III. METHODOLOGY

Nuclear Power Plant building is considered for the analysis. The building is modelled and the response of the building at the floor level has been generated by excitation at ground level as well as at floor levels, in the form of ground response spectra and floor wise response spectra respectively and compared the results. STAAD Pro.V8i has been used to model the building and to generate floor wise responses and the response at each floor levels has been arrived at using SAP 2000. In the next phase the machines of different natural frequency of foundation 1Hz, 3Hz, 5Hz, 7Hz, 10Hz and different weight 1000kN, 5000kN, 10000kN are placed at different floor levels in the building with same plan for all floors as well as different plan for different floors and to analyse the response of the machinery, and finally determine the ideal property of the machinery foundation that can be placed at each floor level.

IV. GENERATION OF FLOOR RESPONSE SPECTRUM(FRS)

Floor response spectrum constitutes the input data for the equipment analysis that might be sitting on the framed structure. A piece of machinery sitting on the floor of a building, if the equipment were supported on the ground level, the ground acceleration spectra should have been used for the analyse the equipment. If the equipment is rest on any particular floor of a building, the analysis of that equipment would need the response spectra data for that floor, which would be considered as a base excitation data for that equipment. This spectra data is known as the floor response spectrum.

Methods of generating FRS are

- Direct Method: Time History Analysis
- Stochastic Analysis
- Simplified Analysis

The direct method is most suitable method and it is used for the FRS generation.

The building is modelled in STAAD Pro.

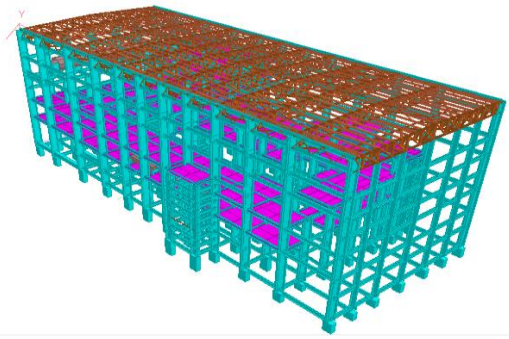

Fig 2:- 3D Model view in STAAD. Pro

The building is analysed using STAAD Pro. by response spectrum method and the responses are obtained. In next step, the Floor wise response spectrum is generated by using the input as shown in fig 3

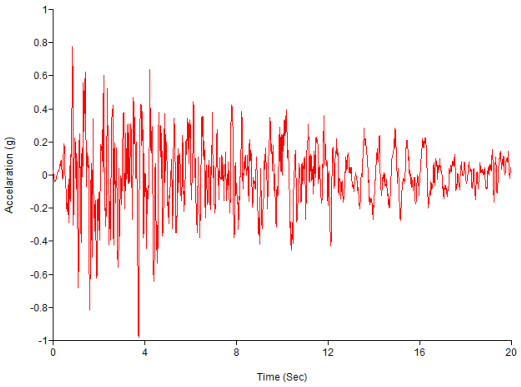

Fig 3:- Input of the FRS generation

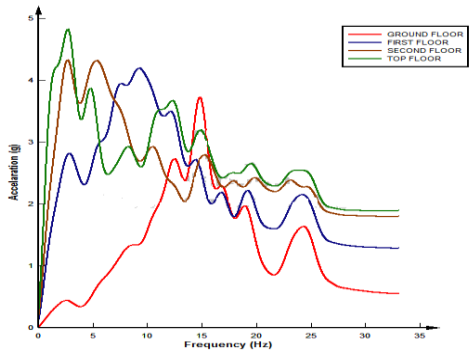

Fig 4 :- Floor Response Spectrum at Different Levels

Fig 4 shows that ground floor response spectrum is of lower value compared to other floors, for upper floors peak value increases rapidly. The highest peak value is obtained at the top floor and lower value is obtained at the ground floor.

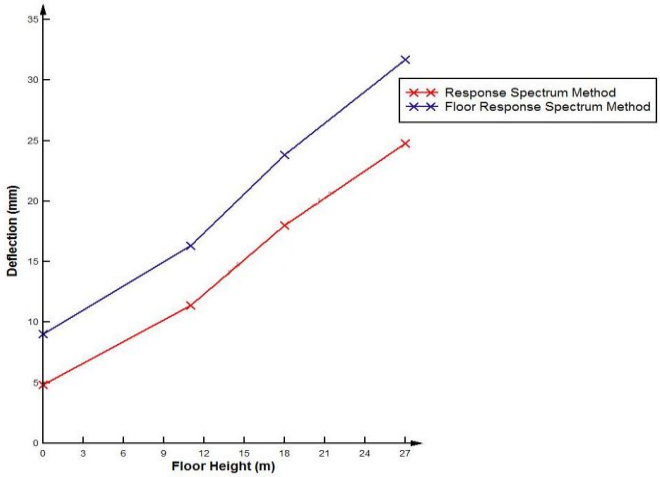

Fig 5:- Comparison of Response Spectrum Method And Floor Response Spectrum Method

In response spectrum method ground floor response spectrum value is used for all floors and the response obtained in each floor is less, compared to Floor response spectrum method. In floor response spectrum method, the floor response is separately generated and assigned to each floor. Here the response obtained is higher than floor response spectrum method. Hence the Floor Response Spectrum is used for analysis of the buildings with heavy machinery.

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V. MACHINERY MODELLING

Machine is modelled as stick model for the purpose of analysis. It is very cheap and can provide direct insights to the overall seismic behaviour of the structure being analyzed. The equipment is simply represented by stick model of columns and beams. The size of the element is determined by its natural frequency and weight of the equipment.

Table 1 Machinery Model details

Weight of Machine (kN)	Natural Frequency of Machinery Foundation (Hz)	Column Size(m)	Beam Size (m)
1000	1	0.9×0.03	1.8×0.04
1000	3	1.7×0.05	2.5×0.08
1000	5	1.6×0.07	2.0×0.06
1000	7	2.2×0.08	2.2×0.05
1000	10	2.2×0.1	2.2×0.06
5000	1	0.9×0.05	1.8×0.04
5000	3	1.9×0.08	2.0×0.1
5000	5	2.7×0.1	2.5×0.08
5000	7	2.5×0.13	2.0×0.04
Weight of Machine (kN)	Natural Frequency of Machinery Foundation (Hz)	Column Size(m)	Beam Size (m)
5000	10	2.6×0.16	2.6×0.06
10000	1	1.1×0.06	1.8×0.04
10000	3	2.7×0.09	2.5×0.08
10000	5	2.5×0.13	2.5×0.08
10000	7	2.6×0.16	2.2×0.05
10000	10	2.7×0.02	2.6×0.06

The each combination of machineries are placed at different floors such as First floor, Second floor, Third floor. Analysed the each model using floor response spectrum method and the responses were obtained. The input of the analysis of machineries in each floor is its corresponding floor response spectra. Responses of different models were then compared and most stable machinery suitable for each floor was determined.

VI. ANALYSIS OF THE MODELS

A. Building with different plan for different floors

The building with different plan for different floors is considered for the analysis. The different combination of machineries of natural frequencies of machinery foundation, 1Hz, 3Hz, 5Hz, 7Hz, 10Hz and different weights 1000kN,5000kN,10000kN are placed at different floors. Analyse the each floor by corresponding floor response spectrum value. The results are obtained as shown in figure

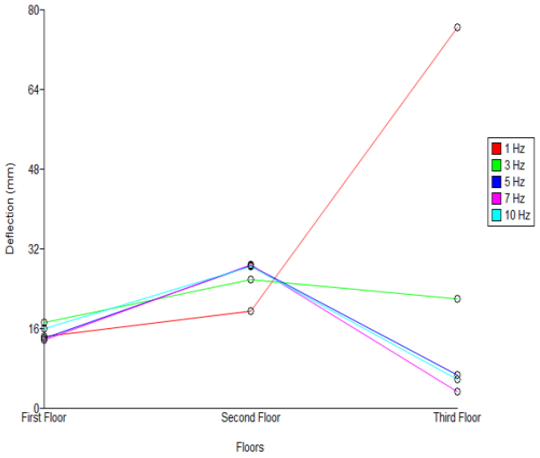

Fig 6:- Deflection of Machineries Weighing 1000kN with Different Natural Frequencies are placed at Different Floors

In Fig 6, it is observed that the minimum deflection is obtained, when 1 Hz frequency machine is placed at first floor. The deflection increases when it is placed at second floor and there is a huge increase in deflection when machinery is placed on third floor due to the presence of resonance at third floor. Hence it is not possible to place the 1 Hz frequency machinery at third floor. In cases of 3Hz, 5Hz, 7Hz and 10Hz frequency machineries, it obtained a maximum deflection in second floor compared to the other floors.

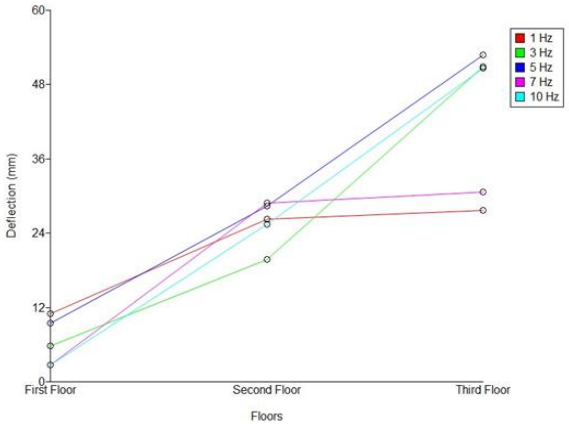

Fig 7:- Deflection of Machineries weighing 5000kN with Different Natural Frequencies are placed at Different Floors

In Fig 7 it is observed that the minimum deflection occurs when the machinery is placed at first floor and the deflection increases when it is placed at second floor. It again increases at third floor. In cases of 3Hz, 5Hz, 7Hz and 10Hz frequency machineries, it obtained a very small deflection at the first floor, compared to the other floors.

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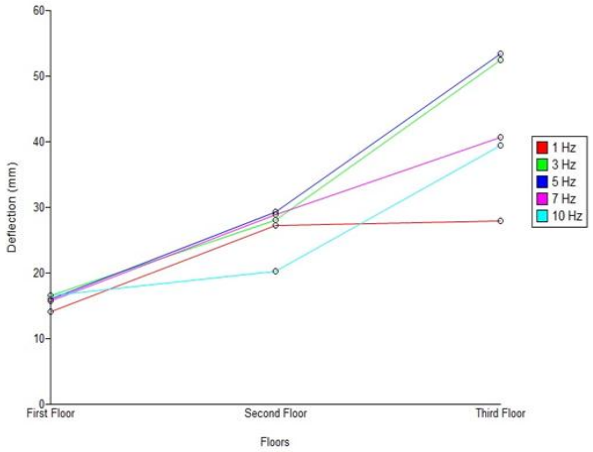

Fig 8. Deflection of Machineries weighing 10000kN with Different Natural Frequencies are placed at Different Floors

In Fig 8 it is observed that the minimum deflection is obtained when the machinery is placed at first floor, the deflection increases when it is placed at second floor and again increases at third floor. In cases of 3Hz and 10Hz frequency machineries, the obtained deflection is almost similar at first floor compared to other frequency machineries.

From the above graphs, it is observed that the most suitable machinery for each floor are obtained as follows

Table 2 Floors and its Corresponding Most Suitable Machinery foundation

Floor	1000kN	5000kN	10,000kN
First floor	5Hz	10Hz	1Hz
Second floor	1Hz	3Hz	10Hz
Third floor	7Hz	1Hz	1Hz

B. Building with same plan for all the floors

The building with same plan for all the floors is considered for the analysis. The different combination of machineries of natural frequencies, 1Hz, 3Hz, 5Hz, 7Hz, 10Hz and different weights 1000kN,5000kN,10000kN are placed at different floors. Analyse the each floor by corresponding floor response spectrum value. The results are obtained as shown in figures

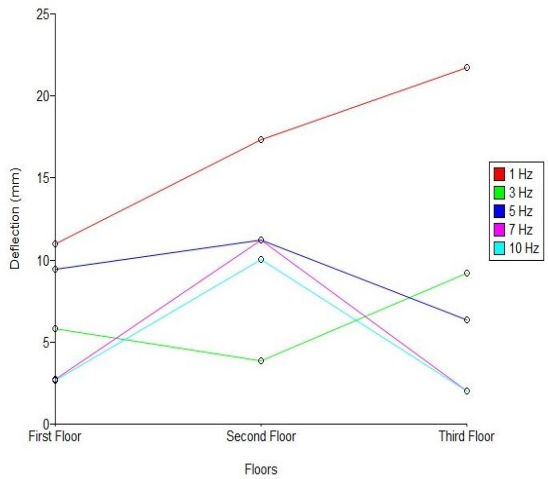

Fig 9:- Deflection when Different Natural Frequency Machineries are placed at Different Floors and Weight of Machineries are 5000kN

In Fig 9, it is observed that the deflection is maximum, when the 1 Hz and 3Hz machinery is placed at third floor, in other frequency machineries the deflection is maximum at second floor. In 3Hz, 7Hz, 5Hz and 10Hz the first floor deflections are of very small value and it is more stable. In 7Hz and 10 Hz machinery the smaller deflection is obtained at third floor

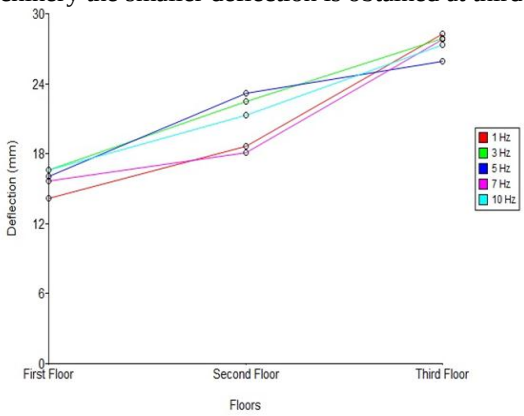

Fig 10:- Deflection of Machineries Weighing 10000kN with Different Natural Frequencies are placed at Different Floors

In Fig 10, it is observed that the minimum deflection is obtained when the machineries are placed at first floor. The deflection increases when it is placed at second floor and the deflection again increases at the third floor.

From the above graphs, it is observed that the most suitable machinery for each floor are obtained as follows

Table 3 Floors and its Corresponding Most Suitable Machinery Foundation

Floor	1000kN	5000kN	10,000kN
First floor	5Hz	10Hz	1Hz
Second floor	1Hz	3Hz	7Hz
Third floor	7Hz	7Hz and 10Hz	5Hz

VII. CONCLUSIONS

- The Building is modelled using STAAD Pro. and floor response spectra for different floors are generated and compared.
- It has been observed that the minimum spectrum value occurs at ground floor and as we move on to top, the value is increased and maximum value is obtained at the top floor.
- The building is modelled using SAP 2000 and analysed using Response spectrum method as well as Floor response spectrum method.
- After comparing both methods, it was observed that the floor level response when subjected to floor wise response spectra is higher than the floor level response when subjected to ground floor response spectra.
- Machinery is modelled using SAP 2000 at different floors like first floor, second floor, third floor and in different natural frequencies like 1Hz, 3Hz, 5Hz, 7Hz and 10Hz, and in different machinery weights like 1000kN,5000kN and 10,000kN using ‘different floor plan’ and ‘same floor plan’.

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- Each machinery model is analysed and varying responses were obtained according to the position of machinery, floor response spectrum of the position of the machinery, natural frequency of the machinery ,stiffness of the floor, Natural frequency of the floor and weight of the machinery.

- It is found that ,a building with same plan at all levels for different weights of machinery considered in the study , that is 1000kN, 5000kN, 10000kN, the natural frequency of machinery foundation 5Hz,10Hz, and 1Hz respectively are ideal for the first floor, 1Hz,3Hz,7Hz are ideal for second floor, 7Hz, 10Hz, 5Hz are ideal for third floor.

- It is found that ,a building with different plan at different levels for different weights of machinery considered in the study , that is 1000kN, 5000kN, 10000kN, the natural frequency of machinery foundation 5Hz,10Hz, and 1Hz respectively are ideal for the first floor, 1Hz,3Hz,10Hz are ideal for second floor, 7Hz, 1Hz, 1Hz are ideal for third floor.

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