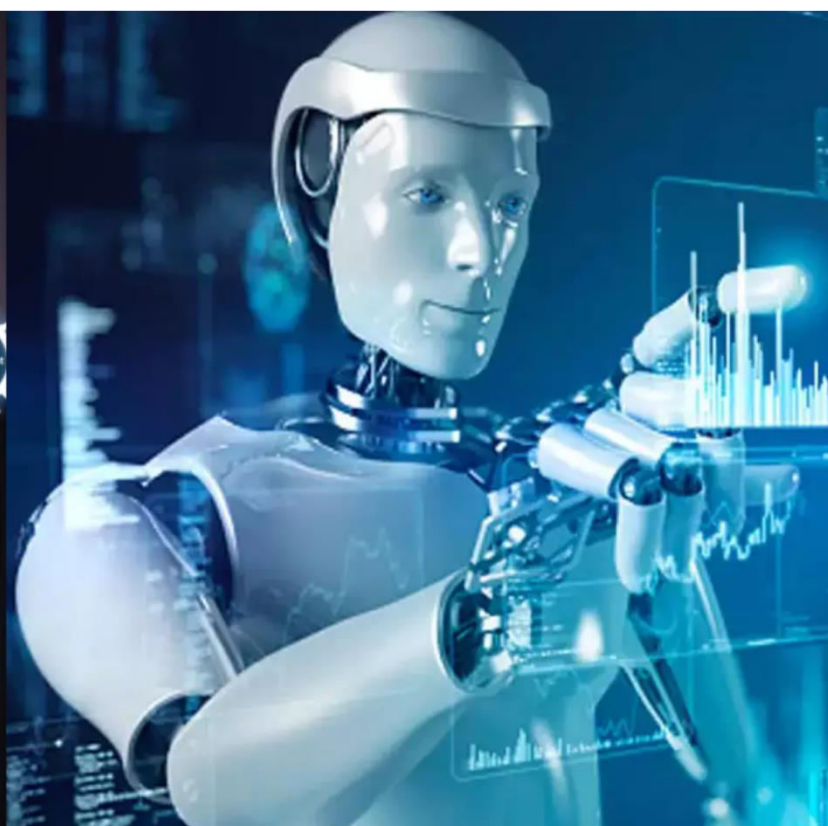




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Dynamic Analysis of Frame-Type Machine Foundation and Integration of Deep Learning

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ABSTRACT: This study presents a novel approach by integrating artificial intelligence with structural engineering for the design and analysis of frame-type machine foundations supporting high-speed machines (15,000 RPM). Using STAAD.Pro for dynamic analysis and SAFE for geotechnical checks, the foundation meets all safety criteria, including resistance to resonance and vibration, as per IS 1893 (2016). A deep learning-based quality check system using the Simple Net algorithm classifies foundation conditions into four categories: safe, minor crack, major crack, and failure. Trained on structural stress data, this AI system enhances accuracy, reduces inspection time, and minimizes human error. The study demonstrates how AI can revolutionize structural engineering through smart, automated analysis.

KEYWORDS: Frame-Type Machine Foundation, Simple Net, Dynamic Analysis, Deep Learning, Automated Inspection.

I. INTRODUCTION

Machine foundations is an essential part of industrial settings which are especially made to support machines which can handle both dynamic load and static load. While ordinary foundations mainly deal with steady forces machine foundations must consider complex effects of dynamic forces generated during operation of the machines. These forces include oscillations, vibrations and rotational impacts, which can influence machines performance and it can even impact stability of the foundation itself. To ensure safety and dependability of the machine and the structure the foundation must be able to withstand seismic forces, which is even more difficult in earthquake prone locations. In machine foundation controlling vibration is very important because it happens when machines operating frequency matches with natural frequency of foundation-soil system. If vibration is not properly managed it will lead to the failure of the structure. To reduce this risk engineers, follow methods like soil compaction, isolation trenches, deep or mat foundations and load counterbalancing. Since it has to absorb dynamic forces which however less than static loads can eventually result in failure if it is left unchecked. The accuracy and efficiency of structural analysis are improved by integrating deep learning into STAADPro for the construction of frame type machine foundation mainly in modal and vibration analysis. In order to ensure the stability of structures under operating circumstances, STAADPro is commonly used to simulate their dynamic behaviour. By incorporating deep learning, the quality evaluation of these foundations can be significantly enhanced. The quality inspection of these foundations can be significantly improved by integrating deep learning. Advanced neural networks that have been trained on large datasets are able to find defects, predict structural performance and optimize design parameters for increased safety and durability. This smart approach makes the design process smoother by automating quality checks, minimizing human errors and ensuing engineering standard is met. As a result, this entire process becomes more reliable, efficient and hassle-free. By merging conventional structural engineering practices with AI-driven inspection, this study offers a smart, efficient, and reliable method for evaluating critical machine foundations, paving the way for advanced automated maintenance and design optimization in structural engineering.

II. LITERATURE SURVEY

Ameer A. Ahmed et.al, 2024 [1]: The safe and proper working of turbomachinery, which causes harmonic loads that can generate vibration that will affect performance, which depends on foundations. These foundations are modelled using the help of numerical programs, but first they should be verified by reference analysis. Load of machine can be reduced to working on top of slab of frame type machine foundation. This study will investigate on

how effect of machine mass elevation (12.6 to 14.2m) on dynamic response of high-speed turbomachine foundation using software ANSYS for analysis in 3D. Hanjie Qian et.al, 2023 [2]: When trying to analyse the microstructure of concrete with the use of Scanning Electron Microscopy (SCM) images, this study will provide an automated segmented method. The method will improve the prediction accuracy, mainly at boundaries, while improving the PointRend deep segmentation technique. With a dataset of 2267 identified particles of cement, Cement past samples with different water cement ratios (0.2 and 0.4) was made and were cured for the duration of 1, 3, 7, 14 and 28 days. This recommended approach performs greater than WEKA, FCN, and original PointRend, and other segmentation algorithms. Hydration degrees are calculated with results of segmentation and the result were in good agreement in water which is nonevaporable approach. Also, there was a little change in irregularity and roundness of the cement particles developed during the time of curing. Faris Waleed Jawad et.al, 2022 [3]: This study makes use of small-scale modelling methods with vertical vibrations to check the risk of soil liquefaction under dynamic loads. Sine wave loads were applied for operating frequencies of 1000, 2500, 3500. Settlement, excess pore water pressure, vertical stress and liquefaction effect is among the important factor that were checked. The result shows that liquefaction mainly happens in loose sandy soil, and that higher frequencies improve vibration load and settlement. Although liquefaction depends on frequency in dense medium soil, was not seen in thick soil. By using a subbase layer which is thicker than 1.5 times the depth of footing liquefaction was reduced properly. V.R. Dhut et.al, 2021 [4]: In industries machine foundation was very important because if they fail it results in huge loss. These foundations are designed in a way that it keeps amplitude to a very small microns and it should withstand both dynamic load and static loads. The soil below influences natural frequency which requires a detailed analysis. In this model it uses elastic half space method and finite element analysis and modelling is done in STAADPro software. With the goal to optimize foundation size for different soil conditions, 3 machines (150,250, 450 rpm) and six soil types was checked and were verified using IS:2974-1982.

III. METHODOLOGY

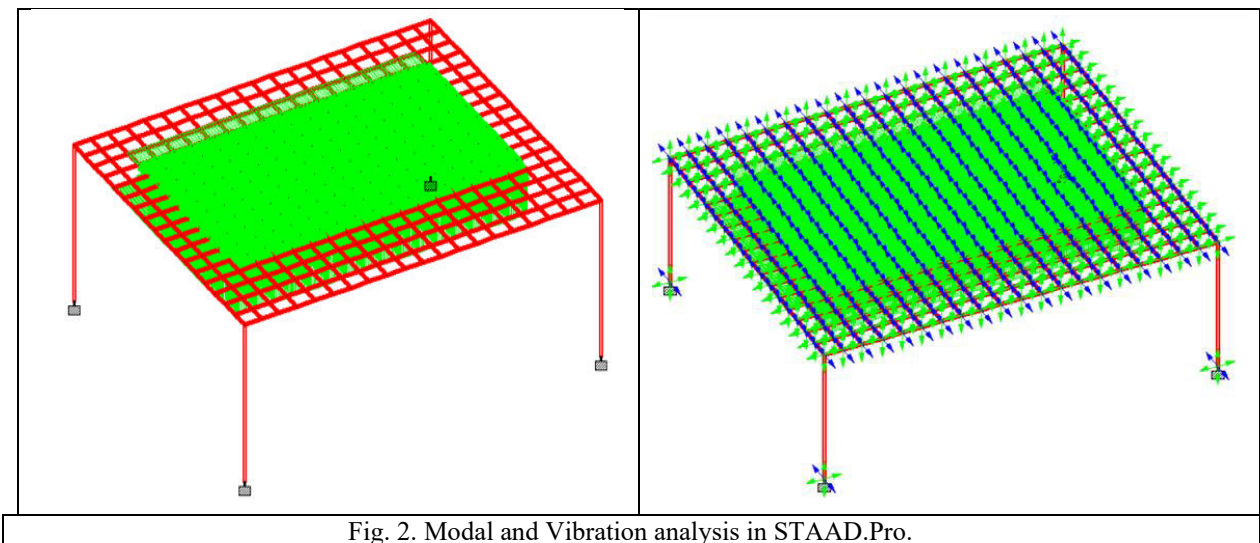
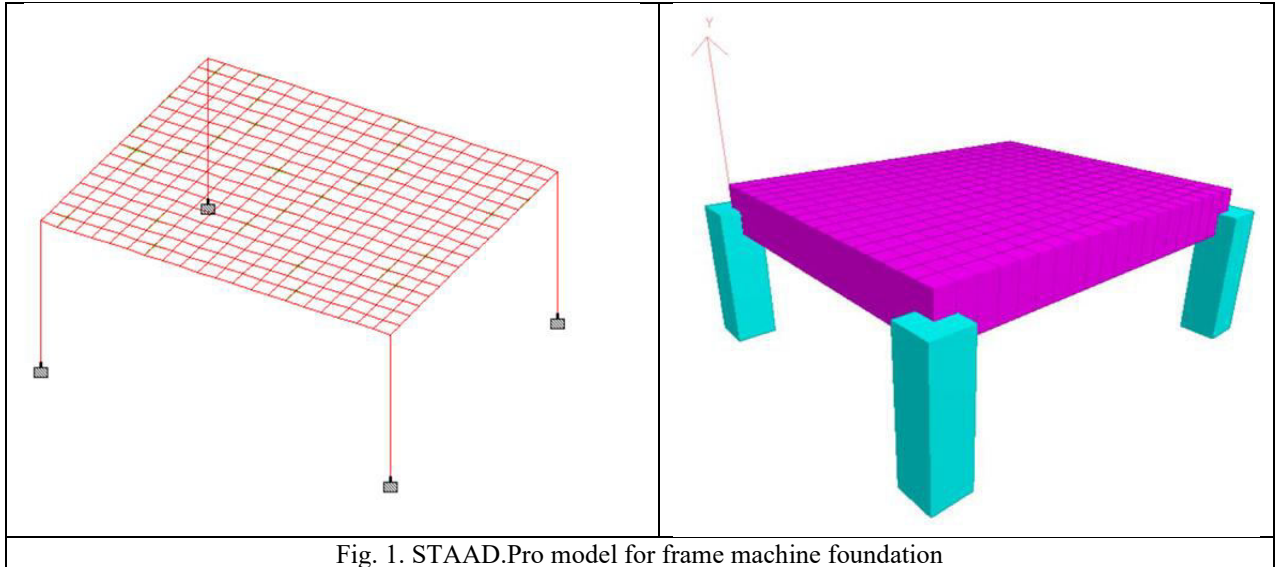
Machine foundation was designed using STAAD.Pro. After completion of model building in STAAD.Pro modal and dynamic analysis is done first and after that using SAFE software SBC check was performed and later on deep learning approach for checking quality of frame type machine foundation was done using algorithm simple net.

Table 1. Project Information

Project type	Machine Foundation
Location	Bangalore
Soil Type	Silty Sand
Safe Bearing Capacity	280 kN/m ²
Operating Speed	15,000RPM
Machine model	FS-Elliot p600+
Live Load	10kN/m ²
Steel	HYSD 500
Grade of Concrete	M45

Structural Analysis In STAAD.Pro:

Model of frame type machine foundation with material property using concrete and steel, and dimension of the foundation designed is 4.04x2.21x0.6, column height is 1.8m and column dimension is 0.5x0.5m.



Modelling in SAFE

To check whether the frame type machine foundation designed here is safe from settlement live load of 208kN/m^2 and dead load of 142kN/m^2 is applied on footing.

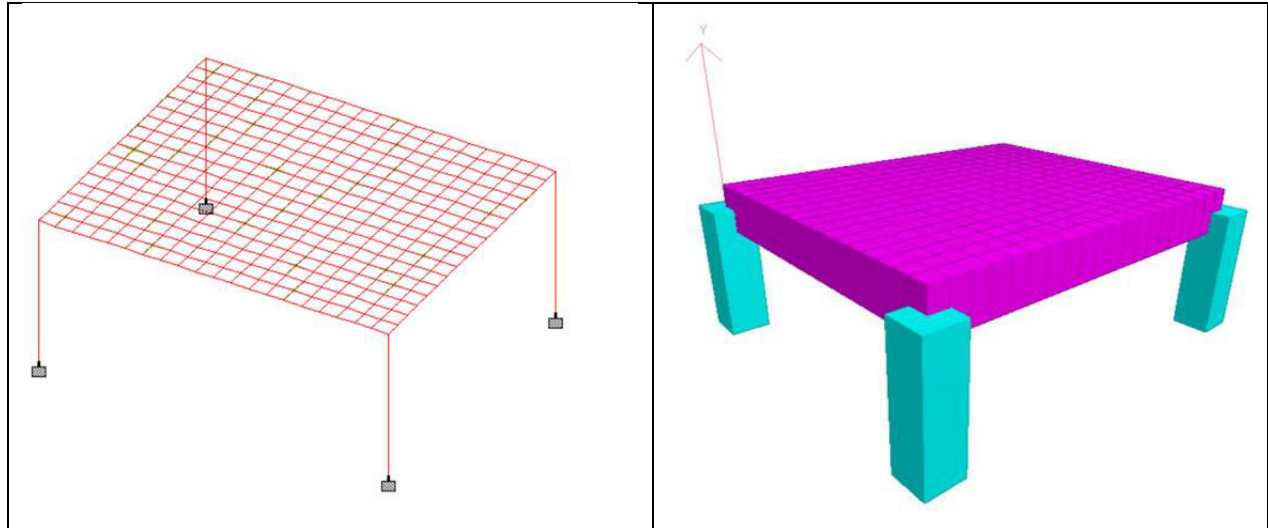


Fig. 3. Modelling in SAFE.

Deep Learning Data

The dataset contains stress values of different load combinations with loads applied varying from 5 to 80 kN/m². A deep learning model is used to check quality of the machine foundation, and the algorithm used for this purpose is simple net. This deep learning model identifies whether the machine foundation is safe, when the cracks will appear through the data set provided.

IV. RESULTS AND DISCUSSION

MODAL AND VIBRATION ANALYSIS

Lowest frequency in this frame type machine foundation is 17.071 Hz. Highest frequency in this frame type machine foundation is 66.000 Hz. Machines operating frequency is 250 Hz. Since frequency does not match the frame type machine foundation designed here is free from resonance. The foundation designed is under tuned. The displacement in the foundations is within acceptable limit. Vertical and horizontal displacements are below 2mm well within acceptable range for machine foundation. Since rotational displacements are very small and values are well under 0.002 rad, there is no risk of tilting or overturning of the foundation. The frame type machine foundation designed here is structurally safe.

Mode	Frequency Hz	Period Seconds	Participation x %	Participation Y %	Participation Z %	Type
1	17.072	0.059	99.895	0.000	0.000	Elastic
2	17.132	0.058	0.000	0.000	99.946	Elastic
3	27.381	0.037	0.000	0.000	0.000	Elastic
4	30.076	0.033	0.000	89.731	0.000	Elastic
5	65.110	0.015	0.000	0.000	0.030	Elastic
6	66.000	0.015	0.080	0.000	0.000	Elastic

			Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	202	1 LOAD CASE 1	1.022	0.483	0.527	1.251	-0.000	-0.000	-0.000
Min X	379	1 LOAD CASE 1	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max Y	211	1 LOAD CASE 1	1.021	0.737	0.531	1.367	-0.000	-0.000	-0.000
Min Y	379	1 LOAD CASE 1	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max Z	330	1 LOAD CASE 1	1.016	0.624	0.532	1.306	0.000	0.000	0.000
Min Z	379	1 LOAD CASE 1	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max rX	5	1 LOAD CASE 1	0.963	0.066	0.489	1.082	0.000	-0.000	-0.000
Min rX	106	1 LOAD CASE 1	0.993	0.176	0.517	1.133	-0.000	-0.000	-0.000
Max rY	306	1 LOAD CASE 1	1.002	0.138	0.506	1.131	0.000	0.000	0.000
Min rY	108	1 LOAD CASE 1	1.006	0.123	0.505	1.132	-0.000	-0.000	-0.000
Max rZ	29	1 LOAD CASE 1	1.012	0.308	0.526	1.182	-0.000	-0.000	0.000
Min rZ	2	1 LOAD CASE 1	0.973	0.057	0.486	1.089	0.000	0.000	-0.001
Max Ra	211	1 LOAD CASE 1	1.021	0.737	0.531	1.367	-0.000	-0.000	-0.000

Fig. 4. Modal And Vibration Analysis

Check For Deflection and Soil Pressure

Check for deflection helps to determine settlement of the foundation. Standard allowable settlement is 25mm. For this Frame type machine foundation observed settlement is 4.94mm. Since 4.94mm is within 25mm limit foundation is safe and stable. Soil pressure should be less than safe bearing capacity of soil which is 280 kN/m². Soil pressure value obtained is 166 kN/m². Since 166 kN/m² is less than 280 kN/m² the structure is safe and stable.

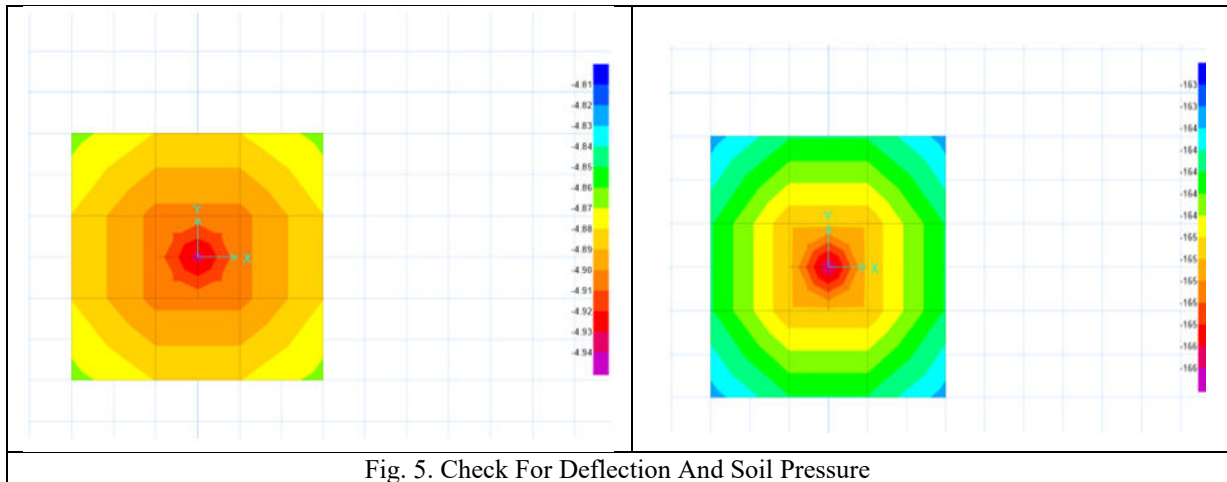


Fig. 5. Check For Deflection And Soil Pressure

Check For Crack

The frame type machine foundation is safe and does not cause any crack. Check for crack was done in Deep learning using algorithm Simple net. The intensity of load applied here is 10 kN/m². The frame type machine foundation is safe for all 9 load combinations.

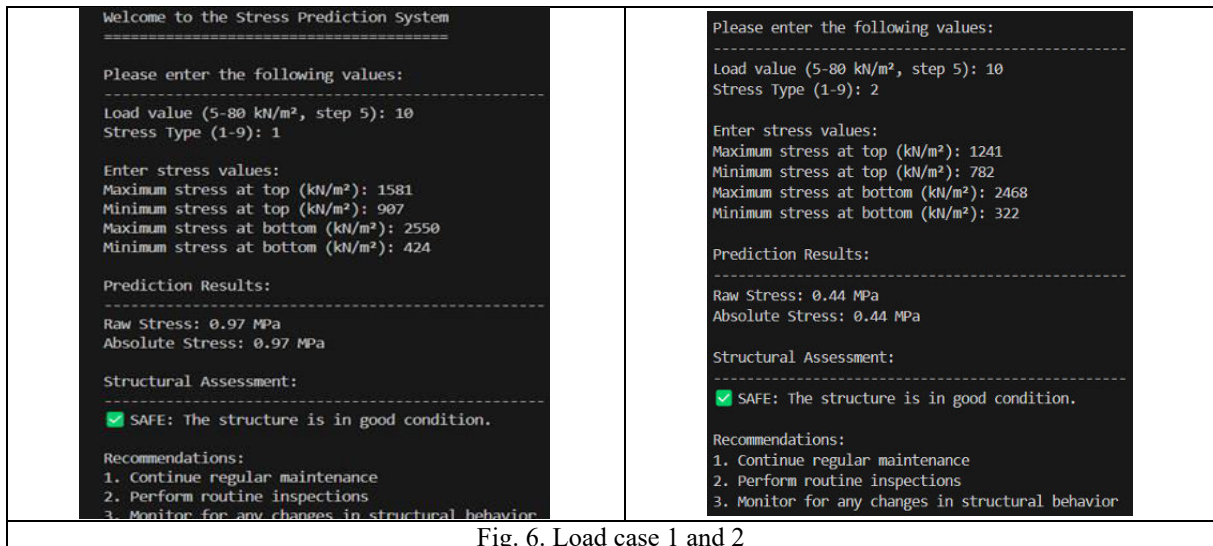


Fig. 6. Load case 1 and 2

<p>Please enter the following values:</p> <p>-----</p> <p>Load value (5-80 kN/m², step 5): 10 Stress Type (1-9): 3</p> <p>Enter stress values:</p> <p>Maximum stress at top (kN/m²): 1241 Minimum stress at top (kN/m²): 782 Maximum stress at bottom (kN/m²): 2468 Minimum stress at bottom (kN/m²): 322</p> <p>Prediction Results:</p> <p>-----</p> <p>Raw Stress: 0.47 MPa Absolute Stress: 0.47 MPa</p> <p>Structural Assessment:</p> <p>-----</p> <p>✅ SAFE: The structure is in good condition.</p> <p>Recommendations:</p> <ol style="list-style-type: none"> 1. Continue regular maintenance 2. Perform routine inspections 3. Monitor for any changes in structural behavior 	<p>Please enter the following values:</p> <p>-----</p> <p>Load value (5-80 kN/m², step 5): 10 Stress Type (1-9): 4</p> <p>Enter stress values:</p> <p>Maximum stress at top (kN/m²): 1240 Minimum stress at top (kN/m²): 768 Maximum stress at bottom (kN/m²): 2388 Minimum stress at bottom (kN/m²): 406</p> <p>Prediction Results:</p> <p>-----</p> <p>Raw Stress: 0.70 MPa Absolute Stress: 0.70 MPa</p> <p>Structural Assessment:</p> <p>-----</p> <p>✅ SAFE: The structure is in good condition.</p> <p>Recommendations:</p> <ol style="list-style-type: none"> 1. Continue regular maintenance 2. Perform routine inspections 3. Monitor for any changes in structural behavior
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Fig. 7. Load case 3 and 4

<p>Please enter the following values:</p> <p>-----</p> <p>Load value (5-80 kN/m², step 5): 10 Stress Type (1-9): 5</p> <p>Enter stress values:</p> <p>Maximum stress at top (kN/m²): 1240 Minimum stress at top (kN/m²): 768 Maximum stress at bottom (kN/m²): 2388 Minimum stress at bottom (kN/m²): 406</p> <p>Prediction Results:</p> <p>-----</p> <p>Raw Stress: 0.67 MPa Absolute Stress: 0.67 MPa</p> <p>Structural Assessment:</p> <p>-----</p> <p>✅ SAFE: The structure is in good condition.</p> <p>Recommendations:</p> <ol style="list-style-type: none"> 1. Continue regular maintenance 2. Perform routine inspections 3. Monitor for any changes in structural behavior 	<p>Please enter the following values:</p> <p>-----</p> <p>Load value (5-80 kN/m², step 5): 10 Stress Type (1-9): 6</p> <p>Enter stress values:</p> <p>Maximum stress at top (kN/m²): 1267 Minimum stress at top (kN/m²): 727 Maximum stress at bottom (kN/m²): 2394 Minimum stress at bottom (kN/m²): 335</p> <p>Prediction Results:</p> <p>-----</p> <p>Raw Stress: 0.55 MPa Absolute Stress: 0.55 MPa</p> <p>Structural Assessment:</p> <p>-----</p> <p>✅ SAFE: The structure is in good condition.</p> <p>Recommendations:</p> <ol style="list-style-type: none"> 1. Continue regular maintenance 2. Perform routine inspections 3. Monitor for any changes in structural behavior
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Fig. 8. Load case 5 and 6

<p>Please enter the following values:</p> <p>-----</p> <p>Load value (5-80 kN/m², step 5): 10 Stress Type (1-9): 7</p> <p>Enter stress values:</p> <p>Maximum stress at top (kN/m²): 1267 Minimum stress at top (kN/m²): 727 Maximum stress at bottom (kN/m²): 2394 Minimum stress at bottom (kN/m²): 335</p> <p>Prediction Results:</p> <p>-----</p> <p>Raw Stress: 0.46 MPa Absolute Stress: 0.46 MPa</p> <p>Structural Assessment:</p> <p>-----</p> <p>✅ SAFE: The structure is in good condition.</p> <p>Recommendations:</p> <ol style="list-style-type: none"> 1. Continue regular maintenance 2. Perform routine inspections 3. Monitor for any changes in structural behavior 	<p>Please enter the following values:</p> <p>-----</p> <p>Load value (5-80 kN/m², step 5): 10 Stress Type (1-9): 8</p> <p>Enter stress values:</p> <p>Maximum stress at top (kN/m²): 1266 Minimum stress at top (kN/m²): 725 Maximum stress at bottom (kN/m²): 2322 Minimum stress at bottom (kN/m²): 406</p> <p>Prediction Results:</p> <p>-----</p> <p>Raw Stress: 0.71 MPa Absolute Stress: 0.71 MPa</p> <p>Structural Assessment:</p> <p>-----</p> <p>✅ SAFE: The structure is in good condition.</p> <p>Recommendations:</p> <ol style="list-style-type: none"> 1. Continue regular maintenance 2. Perform routine inspections 3. Monitor for any changes in structural behavior
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Fig.9 . Load case 7 and 8

<p>Please enter the following values:</p> <p>-----</p> <p>Load value (5-80 kN/m², step 5): 10 Stress Type (1-9): 9</p> <p>Enter stress values:</p> <p>Maximum stress at top (kN/m²): 1266 Minimum stress at top (kN/m²): 725 Maximum stress at bottom (kN/m²): 2322 Minimum stress at bottom (kN/m²): 406</p> <p>Prediction Results:</p> <p>-----</p> <p>Raw Stress: 0.62 MPa Absolute Stress: 0.62 MPa</p> <p>Structural Assessment:</p> <p>-----</p> <p>✅ SAFE: The structure is in good condition.</p> <p>Recommendations:</p> <ol style="list-style-type: none"> 1. Continue regular maintenance 2. Perform routine inspections 3. Monitor for any changes in structural behavior

Fig10. Load case 9

V. CONCLUSION

This study mainly focuses on dynamic analysis of frame type machine foundation is STAADPro software. Check for deflection, check for punching shear and check for soil pressure in SAFE software. In deep learning quality of structure is checked in which it will check whether the structure is safe and detects crack. In the frame type machine foundation designed here it is observed that minimum frequency observed is 17.071Hz, and the maximum frequency observed is 66.000Hz. Machine frequency is 250Hz, since maximum frequency is 66.000Hz which is approximately 73.6% less. Hence foundation does not experience any resonance due to machine frequency. The foundation designed here is under tuned. In this frame type machine foundation, the displacement is within acceptable limit. Vertical and horizontal displacements are below 2mm which is well within acceptable range of machine foundation. Since rotational displacements are very small and values are well inside 0.002 rad, the risk of tilting and overturning of the machine foundation is eliminated. The foundation designed here is structurally safe. By doing check for deflection of the machine foundation it helps in determining settlement of the foundation. Standard allowable settlement is 25mm. For the frame type machine foundation designed here the settlement observed is 4.94mm. Since the observed settlement is 80.24% less than standard allowable settlement of 25mm the foundation is safe and stable. The condition for a foundation or structure to be safe and stable is, soil pressure should always be less than safe bearing capacity of soil, safe bearing capacity considered here is 280kN/m².

The value of soil pressure obtained here is 166kN/m², which is 40.71% less than actual safe bearing capacity of soil. Since soil pressure satisfies the condition, the foundation is safe and stable. The structure is safe and does not cause any crack due to load acting on it. Check for crack was done using Deep learning and simple net algorithm was used. The live load considered here is 10kN/m², and the structure is safe for all the 9 load combinations. No crack will be appeared of the machine foundation till 10kN/m², live load above 10kN/m² will cause cracks. Minor crack will appear if live load is applied more than 10kN/m², and major crack will appear if live load is applied 20kN/m². Structure fails if live load is applied more than 20kN/m².

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