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DESIGN AND DYNAMIC ANALYSIS OF SCREEN SUPPORTING STRUCTURE

PROJEKTOVANJE I DINAMIČKA ANALIZA NOSEĆE KONSTRUKCIJE VIBRO SITA

Originalni naučni rad / Original scientific paper
UDK /UDC:

Rad primljen / Paper received: 17.11.2020

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Keywords
- static analysis
- vibration analysis
- machine supporting structure
- sieving classifier

Abstract

Vibration analysis of the supporting machine helps to improve serviceability and ensures good operating conditions for the equipment. In order to improve its strength and reliability at the design level, it is important to define modal parameters such as natural frequency, mode shape and structural damping properties under varying operating conditions. Modal analysis is a valuable tool for differentiating structural functional attributes. At its maximum recurrence, each structure vibrates at high amplitudes. Vibration assessment should be undertaken to know the structural behaviour of system vibration and to check whether the natural frequency of the structure is kept away from the frequency of the system in order to maintain a strategic distance from collapse. In this paper, a frame is modelled to support a 3.5 MT vibration machine and is analysed for static and dynamic loads. The frequency band is maintained by support conditions and frame stiffness. Stresses are calculated for both anchor bolts and beams. The frequency band is observed to increase with the stiffness of the supporting system. In the study a concrete frame with inverted T-beams is considered in a real structure of LG polymers company and proposed is a new steel beam of I-section between the two inverted T-beams for mounting the sieving classifier. Static, dynamic loads, and operating frequency of the machinery are given by the classifier company as per the machine configuration.

Ključne reči
- statička analiza
- analiza vibracija
- noseća konstrukcija
- sito za separaciju, klasiranje

Izvod

Analiza vibracija noseće komponente mašine doprinosi poboljšanom servisiranju i omogućava dobre radne uslove za rad ostale opreme. Radi poboljšanja čvrstoće i pouzdanosti na nivou projektovanja, važno je definisati modalne parametre kao što su sopstvena frekvencija, oblik moda i karakteristike prigušenja konstrukcije pod promenljivim radnim uslovima. Modalna analiza je dragoceni alat za razlučivanje strukturalnih modalnih funkcionalnih karateristika. Pri čestom ponavljanju, vibracije se u konstrukcijama javljaju sa velikim amplitudama. Potrebno je uraditi procenu vibracija kako bi se znalo ponašanje sistema vibracija konstrukcije i radi provere strateške razlike prirodne frekvencije konstrukcije i frekvencije sistema, kako bi se izbegao kolaps. U radu je modelirana rešetka koja nosi 3.5 MT vibracionu mašinu sa analizom statičkih i dinamičkih opterećenja. Raspon frekvencija je uslovljen osloncima i krutošću rešetke. Naponi su izračunati za vijčane veze i za nosače. Primećuje se porast raspona frekvencija sa porastom krutosti sistema noseće konstrukcije. Razmatra se realna betonska noseća konstrukcija sa okrenutim T nosačima kompanije LG polimeri i predlaže se novi čelični nosač I profila između dva okrenuta T nosača, radi motaže sita za separaciju. Statička i dinamička opterećenja, kao i radna frekvencija u konfiguraciji mašine su podaci dobijeni od kompanije proizvođača vibro-sita.

INTRODUCTION

Structures are designed regularly to sustain their independent dead weight, superimposed loads and adverse environmental effects like wind, etc. Generally, these loads are treated as maximum loads that cannot be changed with time. In certain situations, the load applied not only includes static components, but also time-changing components which are aggressive loads. In the past, the effects of dynamic loading have often been evaluated using a static load equivalent, or an impact factor, or changing the safety factor to a static load.

Numerous advances have been made to try to evaluate the impacts of dynamic loading. Typical situations where it would be important to take into account more accurately the response generated by cyclic loading are vibrations caused by machinery, vehicle-generated loading, loading of cranes, impulsive load produced by impact, seismic tremors or by blasts, dynamic loading effects on high buildings, long bridges and structures in a seismic zone. It is therefore crucial to take into account the changing nature of the system.

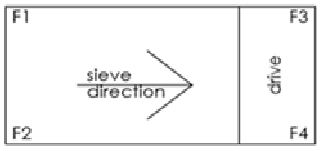
Static analysis is not sufficient to assess the vibration characteristics of the support structure. To determine the dynamic response of the structure, vibration analysis plays a vital role. For each machine supporting the structure, vibration analysis should be carried out whether the structure resists the dynamic forces imposed on it by the mounted machine unit. The rectangular plate is considered and free vibration analysis is performed using the spring model by providing intermediate supports like line, point, uniformly distributed and mixed supports to the spring and simulated.

Based on stiffness a supported vibration response is generated, /1/. Experiments are conducted for modal analysis for beams of different materials like brass, steel, copper, and aluminium, and parameters are derived such as fundamental frequency, mode shape, and excited damping using a hammer of 0 to 2000 Hz frequency response functions using rapid Fourier transformation, /2/. Modal analysis is carried out to assess the fundamental frequency and mode shape of the supporting structure and to perform the AE test, cutting tests which are related to system components /3/. Using the FEA structure, dynamic characteristics such as fundamental frequencies, mode shapes, harmonic response are analysed and obtained, /4/. Normal frequency and mode shapes have been obtained for the F-shaped support system supporting upright drilling machines using FEM, /5/. Performance checks are carried out on a real-time model based on the type of connection (i.e. fixed, pinned and hinged), the loads generated by the system (i.e. static and dynamic loads) and the results are compared, like the deflection of the structure acknowledged by the equipment and structure standards, /6/. Finite element analysis is performed to determine the natural frequency and mode shapes of the radial drilling machine structure, /7/. Design of support structural members, bolt connection and weld connection are done, /8/. Static analysis is performed to determine the optimum forces to be applied to the module using ANSYS, /9/. The supporting structure of the system is evaluated and the behaviour is determined when the unit was active and the design considerations included the type of relation between the unit and the structure, depending on the operation requirement, /10/. The steel structure is modelled and vibration analysis is performed, depending on the dynamic properties of the soil and operating frequency of the unit, and checked until the amplitudes are within the limits specified by the machine company, /11/. For the study and design of machine support structures, a new concept of dynamic participation factor is proposed. Compared with traditional dynamic participation factors, modern dynamic participation factors will accurately indicate the contribution of each mode to machine excitation, /12/. Depending on the stiffness and time period, how the natural frequency and mode shapes vary, and the vibration response of the structure, /13/, theoretical and practical design applications for dynamically loaded structures are discussed, /14/.

In this paper, an increased capacity of screening is to be replaced by the old screening. The supporting system with a steel structure is to be analysed and designed to carry the loading specification defined by the manufacturer. The steel supporting structure interim is to be supported by inverted concrete T-beam. The supporting structure shall be analysed for static load, i.e. dead weight of the supporting structure, screening, and material inside the screening unit. During operating conditions, the supporting structure, including the connections, are subjected to dynamic loads in both vertical and horizontal direction. The main objective of this analysis is to determine the maximum deflection, maximum shear force, maximum bending moment for static loads, and to maintain a frequency band well above 20 %.

METHODOLOGY

A 3.5MT capacity of screening required a support arrangement at a higher elevation of the building, supported by inverted concrete T-beams and columns. The supporting structure shall be designed for worst case with a total weight of 6600 kg. Details of the screening machine loading specification are shown in Fig. 1. The initial trial sections for the supporting structure and its connection to the existing inverted concrete T-beam are shown in Fig. 2. The structure is assessed for static loads using a finite element based program. Response quantities such as maximum deflection, maximum shear force, and maximum bending moment are obtained. Similarly, a dynamic analysis of the supporting structure is carried out in order to achieve the resonance frequency and maximum amplitude at resonance frequency in the operating condition. The thorough approach is shown in Fig. 3. Static analysis is performed in STAAD PRO V8i and ANSYS 19.2, modal analysis and harmonic studies are performed in ANSYS 19.2. Frame model is developed in Solidworks 2015 and imported into ANSYS 19.2 for static, modal, and harmonic studies. Static analysis, modal analysis for free vibration and harmonic response for forced vibration tests are carried out based on two conditions, i.e. empty machine unit, and with the full unit.



X - direction = in sieve direction
Z - direction = vertical to the sieve direction

forces at the supporting points		
STATIC	DYNAMIC	
	in Z-direction	in X-direction
F1=F2= 10 kN F3=F4= 23 kN	F1=F2= 2,2 kN F3=F4= 2,8 kN	F1=F2=F3=F4= 0,15 kN
	exitation frequencies	
	f1 = 4,67 Hz f2 = 9,33 Hz	f1 = 4,67 Hz
Resonance exemption of the substructure > (f2+20%)		

Figure. 1. Details of loads and frequencies at supporting points.

Load points F1 and F2 are considered at a distance of 0.6 m c/c, F3 and F4 are considered at a distance of 3.718 m c/c from inverted T-beam. These loads have multiplying factor of 2.5 for static analysis and 2.0 for dynamic analysis as per client requirement. F1 and F3 are acting on right double I-girder and F2 and F4 on left double I-girder.

Design norms for static and vibration analysis

The two ISMB300 are connected by plates of size 430 × 200 × 20 mm at top and bottom of the two girders to have compound action as shown in Fig. 2. The electrode should confirm to IS-814, E51 (yield stress of 360 MPa and ultimate tensile stress of 510-600 MPa). Hence, the maximum stress in the fillet is 100 N/mm^2. The beam is connected to existing RCC T-beam with 4 through bolts of 20 mm dia. and 450 mm length of grade 5.8 as shown in Fig. 2. Maximum tensile and shear stresses in each fastener are 382 MPa and 26 MPa, respectively.

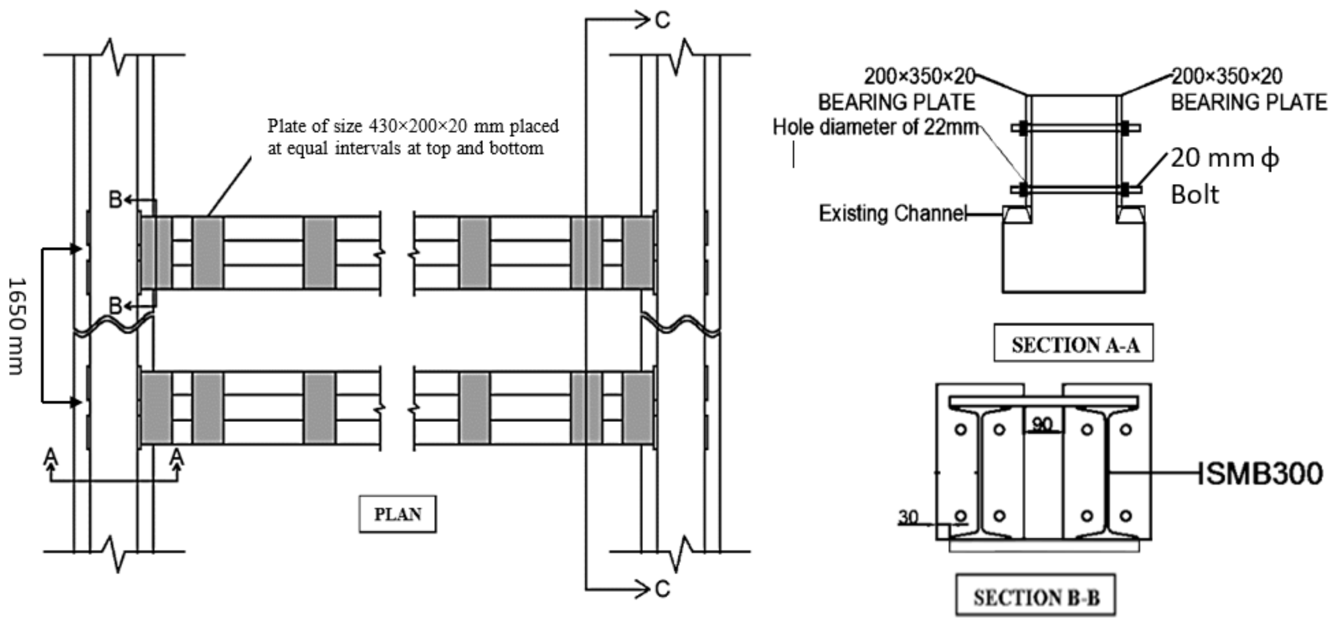


Figure 2. Screening supporting arrangement details.

A face plate of size 350 × 200 × 20 mm is welded to every steel girder. A fillet weld of size 10 mm is used. The location of steel girders connected to the RCC beam.

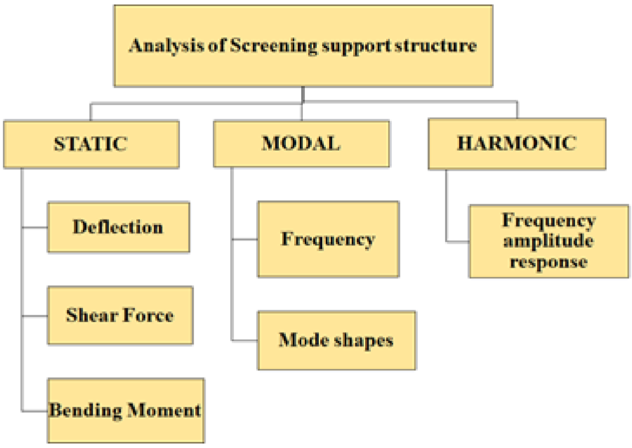


Figure. 3. Methodology for the analysis of screening support structure.

ANALYSIS OF FRAME

Static analysis

The frame is designed to support the 3.5MT. The frame model is analysed for static loads in STAAD Pro V8i.

The maximum static deflection from STAAD Pro at the middle of the girder is 1.716 mm, shown in Fig. 4.

Static analysis shows that the maximum bending moment in the girder is 48.31 kNm, as shown in Fig. 5, and maximal shear force in the girder is 43.76 kN.

Solid model is created for the support structure for 3.5 MT Classifier in Solidworks 2015. Later, ANSYS R19.2 is used to develop the four cases.

Four cases have been considered in order to carry out a parametric study on the static and dynamic analysis of the supporting structure for screening. The selected compound double I section rests on the inverted channel section present on the flange of the inverted concrete T-beam. The supported system must be provided with boundary conditions for the dynamic response of the system. Cases considered for analysis are:

1. Case 1(a): beam boundary with channel section at bottom of the girder.
2. Case 1(b): beam boundary without channel section at bottom of the girder.
3. Case 2(a): frame boundary with channel section at bottom of the girder.
4. Case 2(b): frame boundary without channel section at bottom of the girder.

Table 1 displays the outcome of the static analysis of static loads applied to beams such as deflection, support structure stress and frame connecting bolts.

Figure 6 illustrates clearly how the steel and concrete beams are connected with fasteners and where the boundary condition is used for analysis.

Table 1. Static analysis result using ANSYS.

Design Parameters / Cases	Case 1(a)	Case 1(b)	Case 2(a)	Case 2(b)
Total deformation (mm)	1.804	1.907	1.911	2.257
Stress in support structure (MPa)	81.6	102.1	115.7	150.9
Stress in bolt (MPa)	14.45	40.24	40.77	45.10

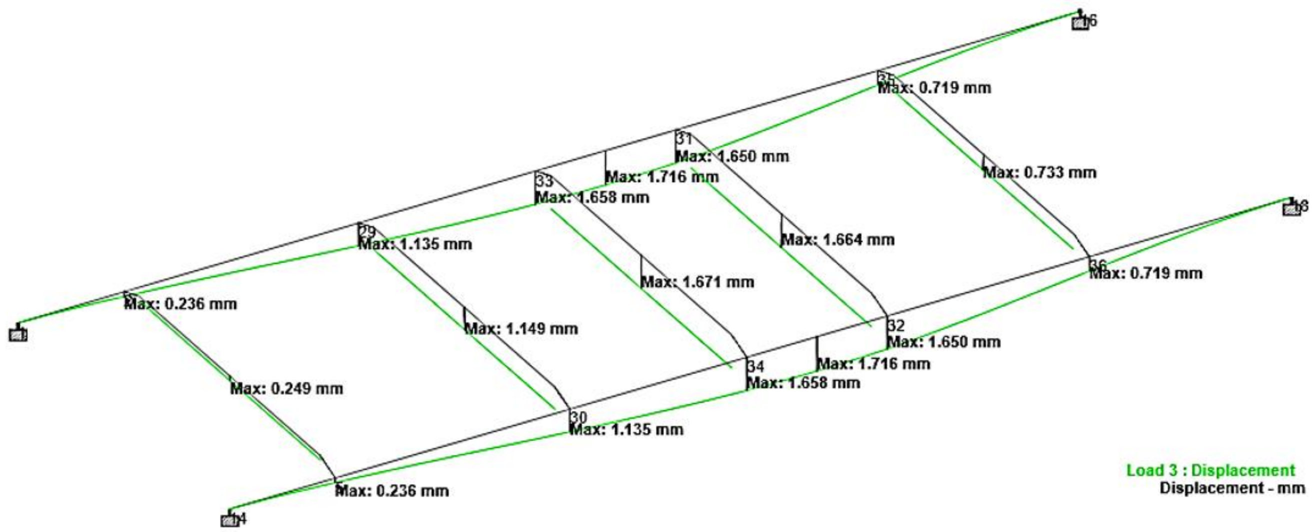


Figure 4. Deflection profile due to static loads.

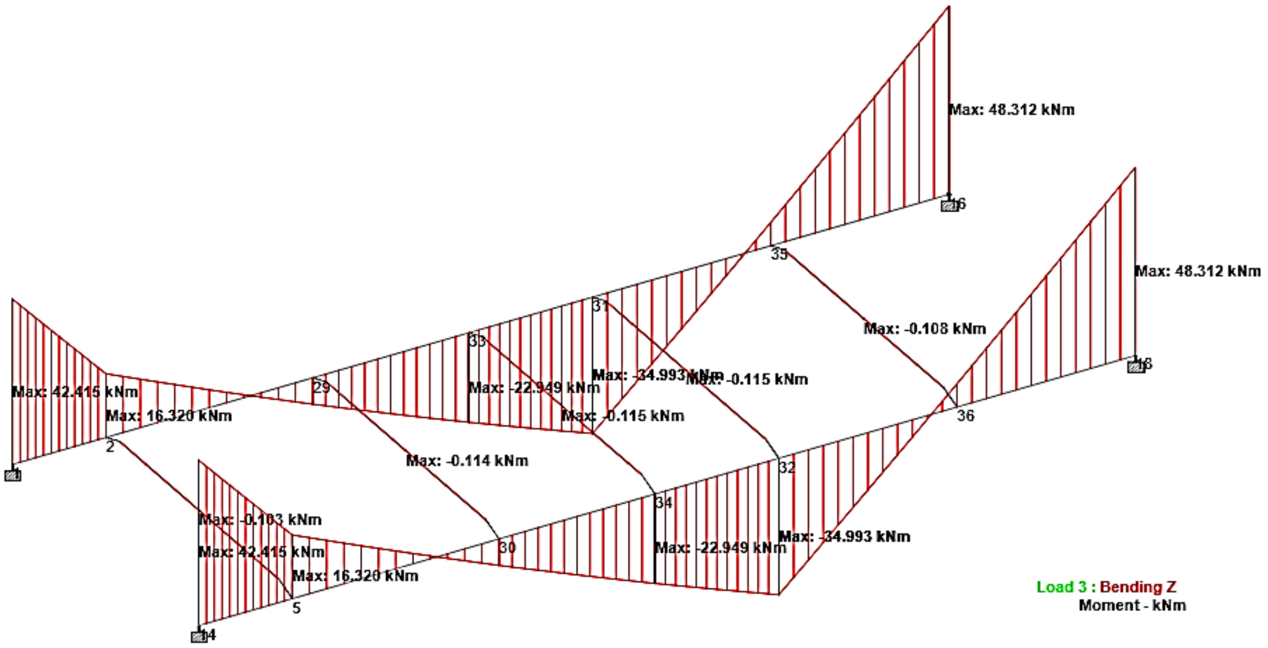


Figure. 5. Bending moment diagram due to static loads.

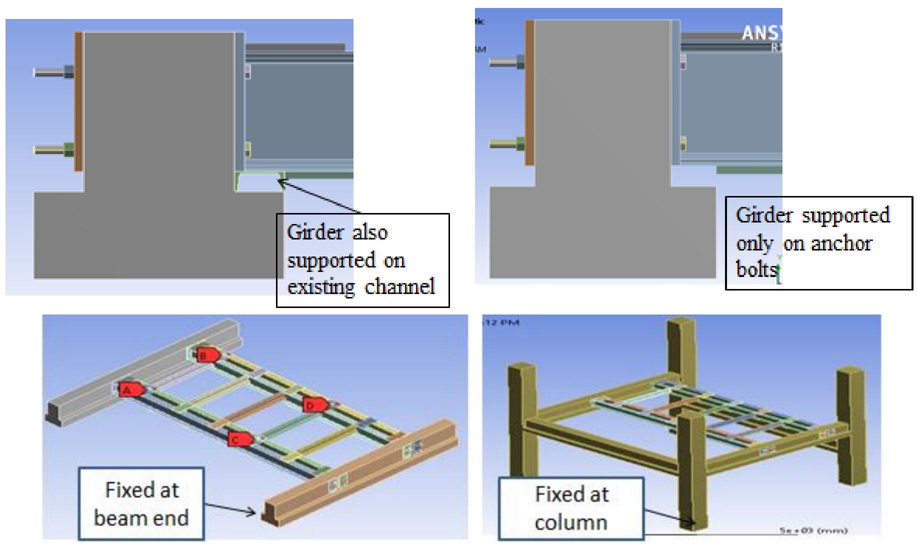
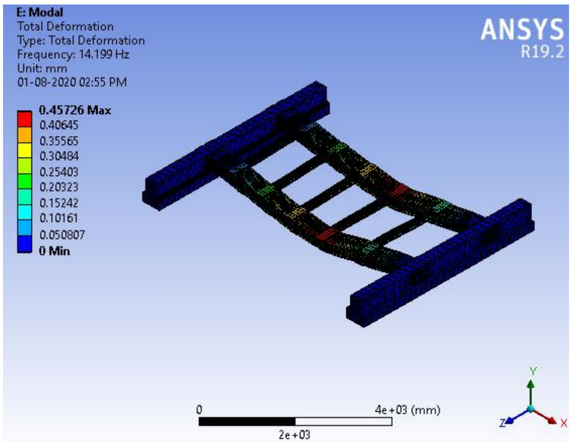


Figure 6. Cases considered for the study in dynamic analysis.

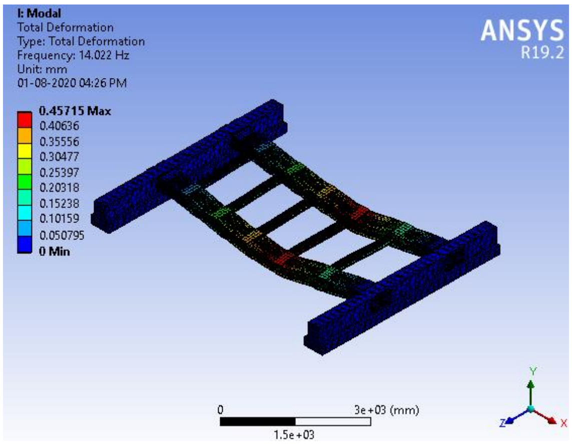
Modal analysis

Modal studies can be carried out on the basis of the fixed boundary condition of the proposed beam, but they cannot be considered because the contact between the proposed compound beams and the existing inverted concrete T-beam is considered to be fixed in STAAD PRO V8i. In real time, they are connected by means of bolts. Real time situation is only possible in ANSYS R19.2. Modal analysis is performed to obtain natural frequency and mode shapes for the system support structure. The three investigations were carried out using ANSYS R19.2. Table 2 presents the first six natural frequencies of the supporting structure for case 1a to case 2b for free vibration, including equipment mass.

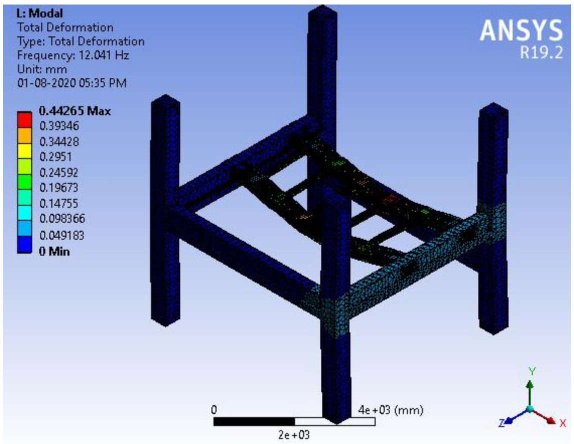
(a)



(b)



(c)



(d)

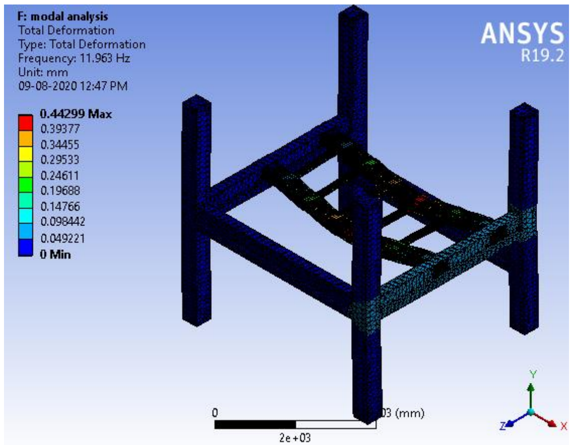


Figure 7. First mode of supporting structure for cases considered: a) case 1(a); b) case 1(b); c) case 2(a); d) case 2(b).

Table 2. First six natural frequencies for free vibration using ANSYS (Modal Analysis).

Mode No.	Modal Frequency (Hz)			
	Case1(a)	Case1(b)	Case2(a)	Case2(b)
1	14.199	14.022	12.041	11.963
2	17.726	17.22	16.631	16.202
3	22.234	21.562	17.731	17.589
4	37.844	36.646	20.632	19.973
5	42.565	42.026	21.724	21.708
6	45.106	44.322	26.012	26.012

In each of these cases, it can be seen from Fig, 7(a-d) that the first mode is in *z*-direction since the stiffness is less in that direction, and there is also a difference in frequency due to the elimination of the channel section at the bottom of girder, from 14.199 to 14.022 Hz and that there could be an increase in time due to columns in the second two cases, thus the frequency of the supporting structure has decreased relative to the first two cases. The fundamental frequency of the supporting structure may change based on the rigidity of the supporting structure and time.

RESULTS AND DISCUSSION

Harmonic analysis for forced vibration

From Fig. 8 it is observed that the maximum amplitude reported is 0.63 mm at a frequency of 17.6 Hz in vertical direction for Case 1a.

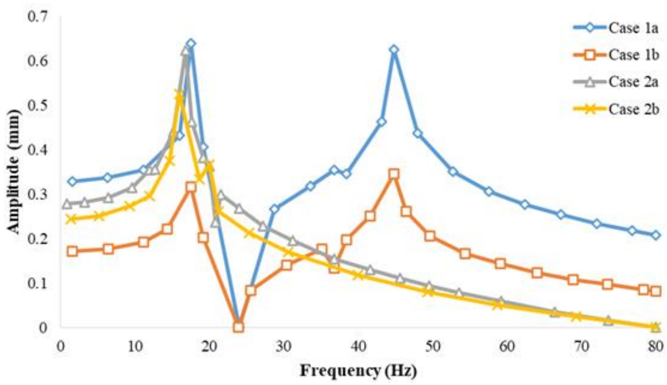


Figure 8. Harmonic response of inverted concrete T-beam for cases considered in vertical direction.

Figure 9 indicates that the maximal amplitude measured is 2.8 mm at frequency of 17.6 Hz in the sieving direction for Case 2b. The reason for considering this case is that the supporting channel may not be present at some point of time.

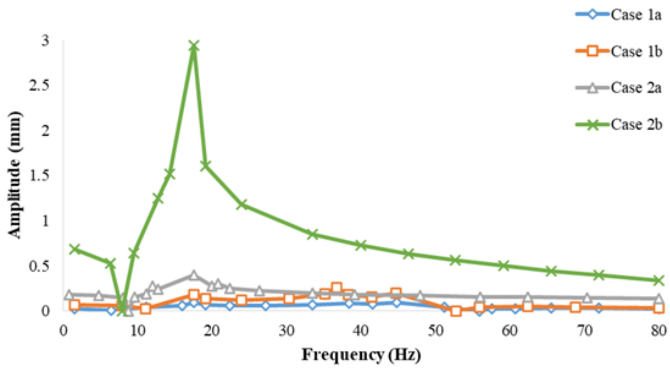


Figure 9. Harmonic response of inverted concrete T-beam for cases considered in sieving direction.

Figure 10 shows that approximately the maximum amplitude observed is 8.41 mm at frequency of 17.6 Hz in the vertical direction for Case 1a of all cases considered.

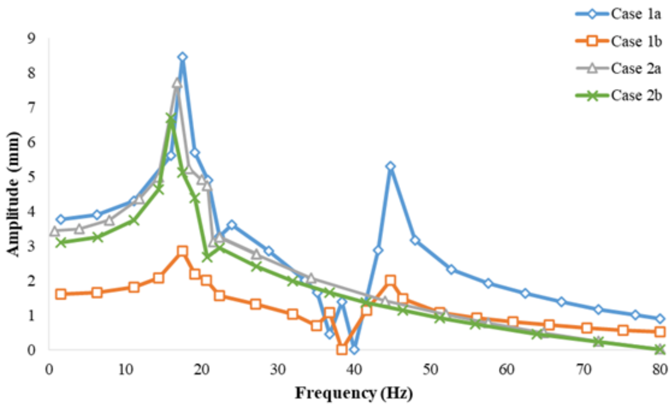


Figure 10. Harmonic response of left double I beam for cases considered in vertical direction.

Figure 11 shows that nearly the maximum amplitude observed is 5.6 mm at a frequency of 17.6 Hz in the sieving direction for Case 2b of all the cases considered.

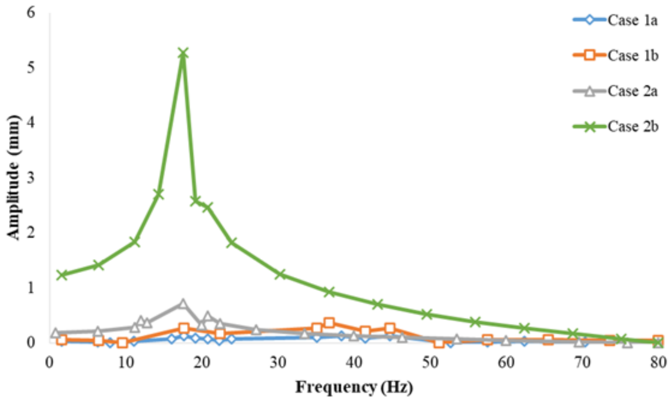


Figure 11. Harmonic response of left double I beam for cases considered in sieving direction.

Out of both beams, the maximum response for the left double I-beam is observed; the graphs are shown in Fig. 10 for response in vertical direction, and in Fig. 11 in sieving direction. Detailed responses from the supporting structural members are shown below.

Response of supporting structure for case 1(a):

Forced vibration response in vertical direction:

(a) Amplitude of inverted concrete T-beam at 16.16 Hz is 0.64 mm.
(b) Amplitude of the left I-beam at 16.30 Hz is 8.41 mm.
(c) Amplitude of the right I-beam at 17.52 Hz is 7.23 mm.

Forced vibration response in sieving direction:

(a) Amplitude of inverted concrete T-beam at 17.6 Hz is 0.09 mm.
(b) Amplitude of the left I-beam at 17.6 Hz is 0.12 mm.
(c) Amplitude of the right I-beam at 17.6 Hz is 0.103 mm.

From the above data for the boundary on the beam without channel section at bottom, the minimum frequency is 16.16 Hz.

Response of supporting structure for Case 1(b):

Forced vibration response in vertical direction:

(a) Amplitude of inverted concrete T-beam at 17.53 Hz is 0.32 mm.
(b) Amplitude of the left I-beam at 17.54 Hz is 2.86 mm.
(c) Amplitude of the right I-beam at 17.54 Hz is 2.46 mm.

Forced vibration response in sieving direction:

(a) Amplitude of inverted concrete T-beam at 17.6 Hz is 0.18 mm.
(b) Amplitude of left I-beam at 17.6 Hz is 0.27 mm.
(c) Amplitude of right I-beam at 17.6 Hz is 0.18 mm.

From the above data for the boundary on the beam without channel section at bottom, the minimum frequency is 17.53 Hz.

Response of supporting structure for Case 2(a):

Forced vibration response in vertical direction:

(a) Amplitude of inverted concrete T-beam at 16.8 Hz is 0.62 mm.
(b) Amplitude of left I-beam at 16.8 Hz is 7.73 mm.
(c) Amplitude of right I-beam at 16.8 Hz is 2.21 mm.

Forced vibration response in vertical direction:

(a) Amplitude of inverted concrete T-beam at 12 Hz is 0.27 mm.
(b) Amplitude of left I-beam at 12 Hz is 0.41 mm.
(c) Amplitude of right I-beam at 12 Hz is 0.29 mm.

From the above data for boundary on frame with channel section at bottom, the minimum frequency is 12 Hz.

Response of supporting structure for Case 2(b):

Forced vibration response in vertical direction:

(a) Amplitude of inverted concrete T-beam at 16 Hz is 0.52 mm.
(b) Amplitude of left I-beam at 16 Hz is 6.70 mm.
(c) Amplitude of right I-beam at 16 Hz is 4.26 mm.

Forced vibration response in sieving direction:

(a) Amplitude of inverted concrete T-beam at 17.6 Hz is 2.94 mm.
(b) Amplitude of left I-beam at 17.6 Hz is 5.29 mm.
(c) Amplitude of right I-beam at 17.6 Hz is 3.56 mm.

From the above data for boundary on frame without channel section at bottom, minimum frequency is 16 Hz.

It is observed that:

- The supporting structure has a maximum deformity of 2.257 mm, and is permissible to deflect L/250 = 24 mm at permissible limits for boundary on a frame without channel section at bottom.
- For 20 mm dia. bolt maximum stress is 45.102 MPa for boundary on frame without channel section at bottom, permissible stress is 500 MPa (384 MPa from calculation) which is in permissible limit.
- Minimum frequency band maintained is 22 % for boundary on frame without channel section at bottom in modal analysis which is greater than 9.33 Hz + 20 %. The support structure is therefore safe from free vibration.
- Minimum frequency band maintained is 22.25 % for boundary on frame with channel section at bottom in harmonic analysis which is greater than 9.33 Hz + 20 %. The support system is protected against induced vibrations in the direction of sieve.

SUMMARY AND CONCLUSION

This paper adopted a 3.5 MT screening support structure analysis based on a finite element analysis. Various design parameters have been used to perform static and dynamic analysis. Based on the study, the structure is designed to withstand loads. The maximum deformation of the support structure under static condition is 2.257 mm. The support structure is designed to maintain a 22.25 % difference in frequency band, which is greater than 9.33 Hz + 20 % (more than 11 Hz) so the structure is safe against forced vibration in the sieving direction. The maximum amplitude of the support system in operating conditions is 8.41 mm. From the study of the transfer of the boundary from the concrete beam to the end of the column, it is concluded that the frequency is reduced. Thus, the true frequency band is obtained by considering the larger boundary. The study related to the channel support at the bottom of the girder reveals that maximum vertical amplitude is increased and frequency is reduced due to increased time period.

ACKNOWLEDGEMENT

Authors thank M/s LG Polymers Ltd. for providing details and specifications of the 3.5MT screening classifier. Authors are also thankful to Dr. Kolluri Kiran for contributing his valuable inputs for this work.

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APPENDIX-I

Design of compound beam

For given static loads, the maximum moment is 48.31 kNm,

$Z_{p.req.} = M\gamma_{m0}/f_y = (48.31\times1.5\times10^6)/(250/1.1) = 318.846$ cm^3; $Z_{p\ req.}$ for single member = 318.84/2 = 159.42 cm^3

Try ISMB 300 @ 44.3 kg/m; Plastic section modulus Z_p = 651.74 cm^3; Hence OK

Factored shear force V = 43.76×1.5 kN; $V_d = A_v f_{yw}/\sqrt{3}\gamma_{m0}$ (clause 8.4 of IS 800 : 2007)

A_v = Shear area = $h\times t_w$ = 300×7.5 = 2250 mm^2

Shear strength $V_d = A_v f_{yw}/\sqrt{3}\gamma_{m0} = (2250\times250)/(\sqrt{3}\times1.1\times10^3)$ = 295.23 kN; $V/V_d = 0.22 < 0.6$

Design moment capacity $M_d = \beta_b Z_p f_y/\gamma_{m0}$; as per cl. 8.2.1.2 of IS 800 : 2007

M_d = 1×651740×250/1.1 = 148.13 kNm > M; Hence SAFE

Design of weld for face plate

Factored S.F. = 1.5×43.76/2 = 32.82 kN; Factored B.M. = 1.5×48.31/2 = 36.23 kNm

Assumed size of weld 10 mm, Area of weld = (2×200×10) + (2×300×10) = 10000 mm^2

Direct stress = 3.28 N/mm^2; Bending stress = 40.25 N/mm^2

Resultant stress = $\sqrt{(3.28^2 + 40.25^2)}$ = 40.38 N/mm^2 < $f_u/\sqrt{3}\times\gamma_{mw}$ = 410/($\sqrt{3}$×1.5) = 157 N/mm^2

Design of bolt

Factored bending moment = 72.46 kNm; Tensile force in bolt = 72.46/150 = 483 kN

Assuming the grade of bolt is 5.8 and diameter = 20 mm; Length of bolt = 450 mm; and 8 bolts

Stress in bolt = (483×10^3)/(314×4) = 384 N/mm^2 < 500 N/mm^2 (from Table 1 of IS 800 : 2007)

Shear force in bolt = 65.64 kN; Shear stress = 26 N/mm^2 < 131 N/mm^2