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Developing a New Vibration Analysis Calculative Method For Esfahan Subway Train and Railways Construction

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Abstract: The simulated mass and spring method evaluation for subway or rail ways construction and installation systems have a wide application in rail industries. This kind of design should be optimizing all related parameters to reduce the amount of vibration in cities, home lands, historical zones and other critical locations. Finite element method could help us a lot to analysis such applications with an excellent accuracy but always developing some simple, fast and user friendly evaluation method required in subway industrial applications.Also process parameter optimization extremely required in rail way industries to achieve some optimal design of rail ways with maximum safety,reliability and performance. also it is important to reduce vibrations and further related maintenance costs as well as possible.This paper develops a simple but useful method simulated mass and spring system evaluation for Esfahan subway construction.

Key words: Subway construction engineering · Natural frequency · Operation frequency · Vibration analysis · Polyurethane layer

INTRODUCTION

The general view of evaluation approach used in this paper introduce with identifying input values like types of rails thickness of rails, foundation characteristics, geology of ground modules, loading parameter, railways geometry and so on. For doing this approach it is important to input all the requested information accurately.This method has two main sub approaches. Recessive approach and vibration approach.both of approach capable to evaluate the whole system characteristics. It is important to identify the bed reaction module accurately before starting both sub approaches. The reaction bed module identification is closed to recessive lamination module identification and that is because of using mass and weight system in subway industries. Both of these modules are a function of polyurethane layer characteristics or installation quality of polyurethane and cabin maximum allowable weight or number of passengers and also quality of cabin. Also it could potentially create different types of frequencies. in usual city subway system with normal quality of ground soil and also acceptable cabin quality it could be supposed to be 0.0036 N/mm^2 for bed reaction module and 2600 N/mm for spring module K in the subway system with mention characteristics like Esfahan subway construction.[1]The natural frequency of the railway could calculate by formula 1 if c' is dynamic module per N/mm calculate by formula 2.also m is spring weights in Kg, E' is dynamic tensile module per N/mm^2, A is load surface per mm^2 and d is recessive layer thickness per mm. damping quantity K and power transfer I also calculate with formula 3 and 4 respectively if η related to damping characteristics also f and f□ related to loading parameter [2].

$$f\square = 1/2\,\pi^2\sqrt{c'/m} \quad (1)$$

$$c' = E'.A/d \quad (2)$$

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$$K = 20\log\left[\sqrt{\frac{1+\eta^2}{\left(1-\left(\frac{f}{f_0}\right)^2\right)^2+\eta^2}}\right] \qquad (3)$$

$$I = 100\left[\sqrt{\frac{1+\eta^2}{\left(1-\left(\frac{f}{f_0}\right)^2\right)^2+\eta^2}}\right] \qquad (4)$$

Also if L represent the distance between two rails (train main shaft length)and R is radius of the train main shaft then increasing of the L/R cause to increase lateral natural frequency. [3] controlling the train operation vibration will help us to reduce operation risks of long machine in several kilometer underground tunnels [4] beside this We should always control the outputs of the vibration method with bed module characteristics and make sure the displacement occur is less than allowable displacements. Then we should first identify all modules and we should perform both dynamic and static analysis. for this purpose the static vibration frequency of rail supposed to be 20 Hz. the results of this evaluation method confirm the laboratory results and this method considering as a parallel way to evaluating the vibrational behavior of subway systems. Also this method is parallel to all vendor graphs in damping layers characteristics Presented in all vendor technical documents [5].

Experimental Details: The mentioned method used in subway train construction of Esfahan and at the end the results compare with other traditional evaluations about all different parameter in this field. The polyurethane layer with 25 millimeter thickness covered completely or surrounding by 12 millimeter thickness two concrete. the live stress due to the train motion tested between 0 and 0.025 N/mm^2 for the rail material and geometry and also all ground characteristics (found in technical document of these kind of train and rail way vendor).the wide of the rail is 2.6 meter, with checking the polyurethane technical documents tables we could loading up to 0.75 N/mm^2 in operation time.The system base whole on mass and spring completely used both in semi deep and deep constructions. The Esfahan subway construction engineering have 40 cm depth for rail system, 70cm traverse gap and slope is 30/1000. Also types of rail are S49. There is also a critical path in this construction engineering. That is because of several historical zone are there between Takhti and Azadi square some of them have more than 500 years old. These buildings and bridges are so sensitive to vibration because of their special paintings, arts and architecture then the group decided to design some kind of light weight and spring damping system in this area. Several different variant tested for this purpose the results will explain in the next sections. the mentioned method used for modeling, simulating and evaluation of the subway construction in Esfahan. for elasticity module of recessive layers evaluation under dead loads group used vendor graphs and it was estimated 0.012N/mm^2 and for dynamic module estimation the frequency supposed to be 20 Hz. the density supposed to 200kg/m^3 all above parameter adjust to limit static displacement less than 4 mm and dynamic displacement less than 3 mm. the lateral share recessive module should be evaluated by the height of lateral recessive profile. We are testing two standard scenario in this matter plan A.250mm planB.360mm [6].

RESULT AND DISCUSSION

The results of vibration and recessive evaluations shown in Tables 1 to 5. Table 1 and 2 showed the recessive and reactionary evaluations of the system. The dynamic and static displacement reduce by increasing the thickness from 40 to 45 cm.this phenomena have two main reasons. The height 5 cm increased and changing in polyurethane layer characteristics.

The results of natural frequency calculation presented in Table 3. the two main factors in such calculation are dynamic module of recessive layer and the weight of the springs system. by increasing in springs system weights the natural frequency decrease considerably. That is why the natural frequency decrease in operation condition comparative to rail natural frequency without train loading.Then it is strongly recommended to adjust dynamic characteristics of recessive layers to fix the rail natural frequency of rail system. We should always keep this important item less than 18 Hz.on the other hand increasing in lateral profile dimension cause slight increase in rail line natural frequency. That is because of increasing in effective bed dynamic module of the system due to such dimension changings. Table 3 shows that with increasing axial load

Table 1: linear displacement and other subway instruction characteristics of deep tunnels - polyurethane layer thickness equal to 25 mm

Upper thickness cm	Spring coefficient lateral elastic layer KN/mm	Bed module static N/mm^3	static Spring coefficient KN/mm	Dynamic Basic bending index mm	Static Basic bending index mm	Dynamic Rail displacement mm	Static Rail displacement mm	Static pressure on recessive Layer N/mm^2 Operation condition	Static pressure on recessive Layer N/mm^2 Only rails	Axial load ton
40	1.433	3650	2.85	3476	3639	2.94	3.39	0.0243	0.012	12.5
45	1.433	3790	2.96	3762	3937	2.65	3.08	0.0237	0.012	12.5
40	1.433	3500	2.73	3515	3679	3.41	3.93	0.0257	0.012	14
45	1.433	3550	2.77	3824	4002	3.13	3.65	0.025	0.012	14

Table 2: linear displacement and other subway instruction characteristics of semi deep tunnels - polyurethane layer thickness equal to 25 mm

Upper thickness cm	Spring coefficient lateral elastic layer KN/mm	Bed module static N/mm^3	static Spring coefficient KN/mm	Dynamic Basic bending index mm	Static Basic bending index mm	Dynamic Rail displacement mm	Static Rail displacement mm	Static pressure on recessive Layer N/mm^2 Operation condition	Static pressure on recessive Layer N/mm^2 Only rails	Axial load ton
40	2.006	3650	2.85	3476	3639	2.94	3.39	0.0243	0.012	12.5
45	2.006	3600	2.91	3742	3995	2.55	3.13	0.025	0.012	12.5
40	2.006	3500	2.73	3515	3679	3.41	3.93	0.0257	0.012	14
45	2.006	3550	2.77	3824	4002	3.13	3.65	0.025	0.012	14

Table 3: Natural frequency and vibration damping criteria in 60 Hz Esfahan subway construction characteristics

considerations	Vibration reduction dB	Natural frequency Hz for dynamic train	Natural frequency Hz For static train	Dynamic Rail displacement mm	Static rail displacement mm	Axial load ton
Lateral profile height equal to 350 mm	-20.2	17.7	20.8	2.65	3.08	12.5
Lateral profile height equal to 250 mm	-20.6	17.2	20.4	2.65	3.08	12.5
Lateral profile height equal to 350 mm	-20.0	17.9	20.8	3.13	3.65	14
Lateral profile height equal to 250 mm	-20.2	17.6	20.4	3.13	3.65	14

Table 4A: Natural frequency and vibration reduction as a function of deep tunnel frequency and lateral profile height equal to 250 mm with axial load equal to 12.5 ton

I(equation 4)%	K(equation 3)dB	frequency	System natural frequency in operation condition	System natural frequency only rails
-101	6.1	12.5	17.2	20.4
-299	12	16	17.2	20.4
-137	7.5	20	17.2	20.4
9	-0.9	25	17.2	20.4
55	-7	31.5	17.2	20.4
75	-12.2	40	17.2	20.4
85	-16.5	50	17.2	20.4
91	-20.6	63	17.2	20.4
94	-24.5	80	17.2	20.4
96	-28	100	17.2	20.4
97	-31.3	125	17.2	20.4
99	-40.8	250	17.2	20.4

Table 4B: Natural frequency and vibration reduction as a function of deep tunnel frequency and lateral profile height equal to 250 mm with axial load equal to 14 ton

I(equation 4)%	K(equation 3)dB	frequency	System natural frequency in operation condition	System natural frequency only rails
-103	6.2	12.5	17.6	20.4
-306	12.2	16	17.6	20.4
-130	7.2	20	17.6	20.4
11	-1	25	17.6	20.4
56	-7.1	31.5	17.6	20.4
76	-12.3	40	17.6	20.4
85	-16.6	50	17.6	20.4
91	-20.7	63	17.6	20.4
94	-20.6	80	17.6	20.4
96	-28.1	100	17.6	20.4
97	-31.4	125	17.6	20.4
99	-40.8	250	17.6	20.4

Table 5A: Natural frequency and vibration reduction as a function of semi deep tunnel frequency and lateral profile height equal to 360 mm with axial load equal to 12.5 ton

I(equation 4)%	K(equation 3)dB	frequency	System natural frequency in operation condition	System natural frequency only rails
-93	5.7	12.5	17.2	20.4
-271	11.4	16	17.2	20.4
-167	8.5	20	17.2	20.4
2	-0.1	25	17.2	20.4
52	-6.5	31.5	17.2	20.4
74	-11.7	40	17.2	20.4
84	-16.1	50	17.2	20.4
90	-20.2	63	17.2	20.4
94	-24.1	80	17.2	20.4
96	-27.7	100	17.2	20.4
97	-31	125	17.2	20.4
99	-40.5	250	17.2	20.4

Table 5B: Natural frequency and vibration reduction as a function of semi deep tunnel frequency and lateral profile height equal to 360 mm with axial load equal to 14 ton

I(equation 4)%	K(equation 3)dB	frequency	System natural frequency in operation condition	System natural frequency only rails
-95	5.8	12.5	17.6	20.4
-278	11.5	16	17.6	20.4
-159	8.3	20	17.6	20.4
4	-0.3	25	17.6	20.4
53	-6.6	31.5	17.6	20.4
74	-11.8	40	17.6	20.4
84	-16.2	50	17.6	20.4
90	-20.3	63	17.6	20.4
94	-24.2	80	17.6	20.4
96	-27.7	100	17.6	20.4
97	-31.1	125	17.6	20.4
99	-40.5	250	17.6	20.4

from 12.5 to 14 ton. there is no considerable changing in natural frequency of the system and this item almost constant during this increasing in axial load. the vibration damping criteria in operation frequency is 60 Hz and indicate in table 3. Vibration damping criteria is almost 20 decibel for mentioned historical zone. the results will confirm the suitability of mentioned items adjusting for construction condition in this critical subway rail line [7].

Damping vibration system also shown in Tables 4 and 5 between the frequency band 0-200 Hz.damping criteria calculated by formula 4 mentioned before. Damping characteristics increased by increasing in frequency.in the natural frequency range the vibration amplitude increasing considerably by increasing in train loading. These phenomena continue up to resonance frequency that is equal to 1.414f□ but fortunately decrease after passing resonance and damping started.the line frequency always should be passing the natural frequency in an extremely short period of time. [8]and also line frequency should be much far away than natural frequency to avoid resonance in any further train condition as well as possible.due to the results explained in Table 4 and 5 it is strongly recommended that the line and train natural frequency keep under 18 Hz in any subway application in Esfahan subway construction (it is also possible to keep this parameter around 15 Hz). [9] as mentioned before the line and train operation frequency is around 25 Hz that is much far than the designed natural frequency (15 Hz). therefore we could adopted all the operation criteria like displacements and stresses with vibration criteria like natural frequency, operation frequency and damping in railway system using polyurethane layer.[10]also it is strongly recommend to increase the polyurethane layer up to 37 millimeter in critical historical zone between Takhti and Azadi square to protect harmful effects of subway vibration transfer to historical bridges and buildings as well as possible [11-14].

CONCLUSION

In this paper a calculative method introduce for subway construction engineering vibration analysis. first the related formulations and equations introduced (I or

K=f (f(Hz)). after that a case history related to Esfahan subway construction and its critical line (historical zone vibration considerations) explained in details.finally the adaptation of these results with other commercial methods discussed in details and the calculative method successfully performed. both results confirm that with designing suitable rail ways dimension and material also adjusting and controlling the loading condition of cabins (with cabins quality and dimensions) and also polyurethane layer thickness and characteristics, we could keep the subway natural frequency around 18 Hz. these kind of process parameter optimization could protects all historical buildings and bridges from any potential harmful vibration generated by subway trains in any further operation times. these results only consist of vibration generating by subway operation and the vibration generated by construction machinery or any possible explosive activity should be design and limits by parallel investigations.

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