University of Banja Luka I Faculty of Architecture, Civil Engineering and Geodesy
ISSN 2712-0570 I UDC 72

Online first version

AGG+

2024_12(1)

AGG+ Journal for Architecture, Civil Engineering, Geodesy and Related Scientific Fields
АГГ+ часопис за архитектуру, грађевинарство, геодезију и сродне научне области

002-014

Categorisation I Review scientific paper
DOI I 10.61892/AGG202401R
UDC I XXXXXXXXXXXXXXXXX
Paper received I 17/11/2023
Paper accepted I 11/02/2024

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DETERMINATION OF THE RESPONSE SPECTRA OF THE SUPERSTRUCTURE OF LENGTH L=3X63.0 M

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DETERMINATION OF THE RESPONSE SPECTRA OF THE SUPERSTRUCTURE OF LENGTH L=3X63.0 M

ABSTRACT

During a seismic impact, the main emphasis is placed on the damage to bridge piers, which were isolated from the horizontal earthquake detector. Accordingly, when calculating the bridges, the reaction spectra obtained from the horizontal earthquake detector are used both for the piers and for the superstructure. The issue of seismic resistance of bridges is very important, especially for superstructures with long spans. It is necessary to construct dynamic curves of seismic resistance for superstructures of a specific system. The article deals with composite steel and concrete continuous span superstructure with a scheme L=3x63.0 m, on which we performed seven real earthquake records for all three categories of soil using the direct dynamic method and built the reference response spectra. Based on the obtained response spectrum and the methodology provided by different normative documents, the calculation of the selected superstructure was carried out, and the force values were determined. **Discussion:** On the basis of the results obtained with the reference response spectra and the curves given in the normative documentation, graphs were drawn, and composite steel and concrete continuous span superstructure with a scheme L=3x63.0 m of the vertical response spectra was determined.

Key words: *superstructure frequency, period, vertical response spectrum*

1. INTRODUCTION

On the basis of the spectral theory of seismic resistance, the determination of the dynamic response spectra processed in all normative documents, which is based on the results obtained by the calculations of the vertical single-mass cantilever system, does not take into account the very diverse calculation schemes of different constructions. Despite the bridges and all other structures of any system, as well as the system itself, the stiffness and mass difference curves are always unchanged and universal, which, in our opinion, is a very big assumption and is far from reality.

In 2012, New York University professors published an article focusing on the importance of the proper selection of a seismic vertical detector for the superstructure of a bridge [1].

In 2018, lowa State University professors published an extensive paper in which they pointed out that the vertical component of the three components of an earthquake is partially ignored by the use of mitigation coefficients in the regulations, which ultimately yields results that are inconsistent with reality. The partial disregarding of the vertical component of the earthquake is due to three main reasons: 1) the amplitude of the vertical acceleration of the ground is small compared to the amplitude of the horizontal acceleration; 2) peak values of three-component accelerations are lost in time; 3) buildings are characterized by much higher rigidity in the vertical direction [2].

The first two reasons are fair but not always true: there are different types of earthquakes, especially in the vicinity of 50 km from the epicentre, and the vertical coefficient is larger than the horizontal one [3].

The third reason is an acceptable consideration for industrial and civil buildings because the buildings in the vertical direction have great stiffness, and for them, the horizontal components are really dominant, whereas in bridge construction, the vertical ground accelerations can have a significant impact on the stress-deformed state of bridge structures.

Therefore, it is necessary to determine the coefficients of seismic dynamism for the composite steel and concrete continuous span superstructure with a scheme L=3x63.0 m.

2. METHODOLOGY

Figures Composite steel and concrete continuous span superstructure with a scheme L=3x63.0 m consist of two main beams, longitudinal and transverse connections. A reinforced concrete slab is used in the roadway part, which is connected to the main coils with beams. The clearance of the bridge deck is 11.5 m, of which the width of the lane of the carriageway is 7.5 m, the width of the safety lanes is 2.0 m, the width of the sidewalks is 1.5 m, and therefore the total width of the cross-section of the superstructure is 15.90 m. the thicknesses of the lower and upper belt of the main beam are different in different cross-sections and accordingly the stiffnesses are also different (Fig.1).

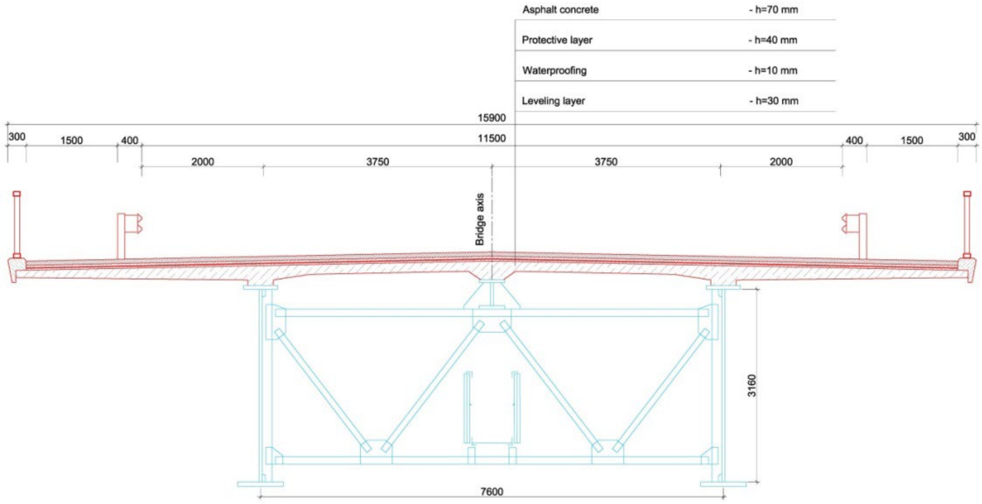


Fig. 1 Cross section of the superstructure with a scheme L=3x63.0 m (Drawing by the authors)

For the superstructure, the frequencies and modal periods for the first three forms of oscillation were determined (Table 1).

Table 1. frequencies and periods of superstructure

L=3x63.0 m			
Oscillation form	Circular frequency rad/s	Frequency 1/s	Period S
1	2	3	4
1	6.26	0.996	1.004
2	11.412	1.816	0.551
3	50.210	7.991	0.125

After fundamental periods and natural frequencies of superstructure were determined for each soil category, seven accelerograms with oscillation periods closest to the fundamental period of a superstructure were selected from the database of accelerograms.

Earthquake peak accelerations have different magnitudes in mutually orthogonal directions. Since the vertical component is dangerous for the superstructure, therefore, such records of vertical oscillation were selected, the oscillation period of which is as close as possible to the fundamental periods of the superstructure.

For this purpose, various accelerograms were selected from the accelerogram, whose main phases were decomposed into harmonics. Harmonics further allows the selection of the specific accelerogram from several accelerograms.

The calculation model of the superstructure was generated using structural analysis and design software MIDAS Civil (Fig. 2). The accelerations of the superstructure were determined using the direct dynamic method. The acceleration spectra were calculated based on the software SeismoSignal 2023.

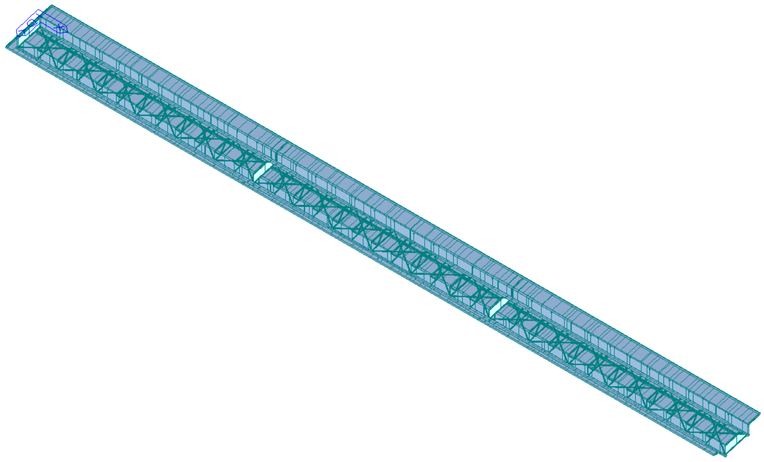
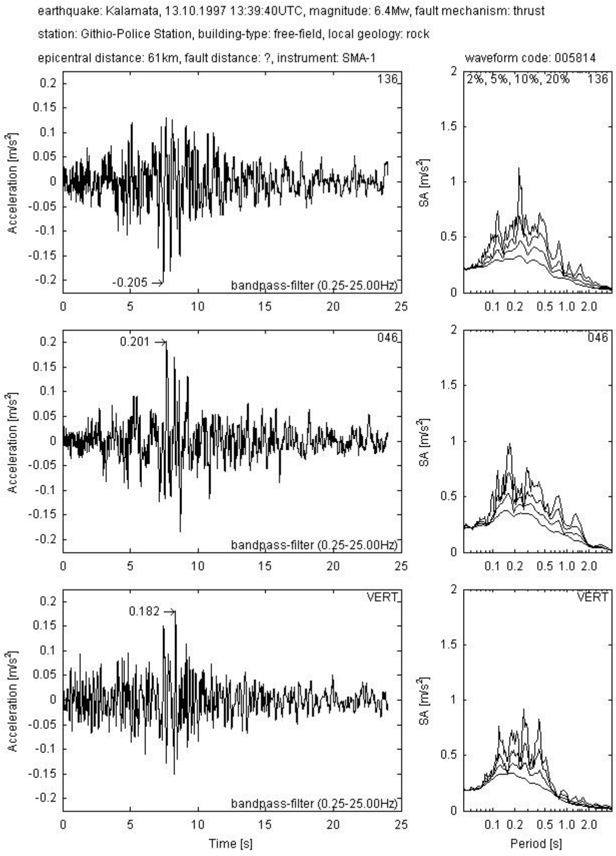


Fig. 2. The reference model of the superstructure of the scheme L=3x63.0 m (Drawing by the authors)

To determine the acceleration spectrum, the real record of the three-component ‘’Kalamata’’ earthquake–accelerogram was used (Fig.3). The vertical component of the accelerogram was separated and normalized in order to exclude the magnitude factor (Fig. 4).



Margaris, B.(2001)

Fig 3. Kalamata earthquake record (code: 005814) (Drawing by Internet-Site for European Strong-Motion DataBase)

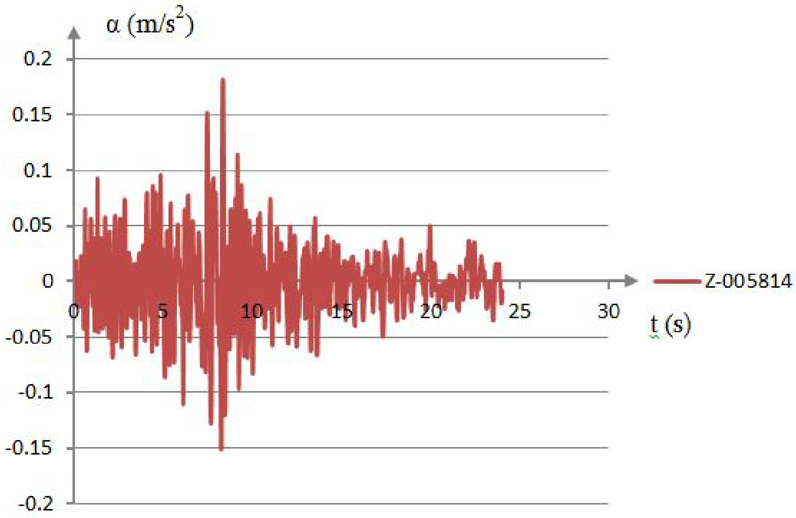


Fig. 4. Vertical accelerogram of the Kalamata earthquake (code: 005814) (Drawing by the authors)

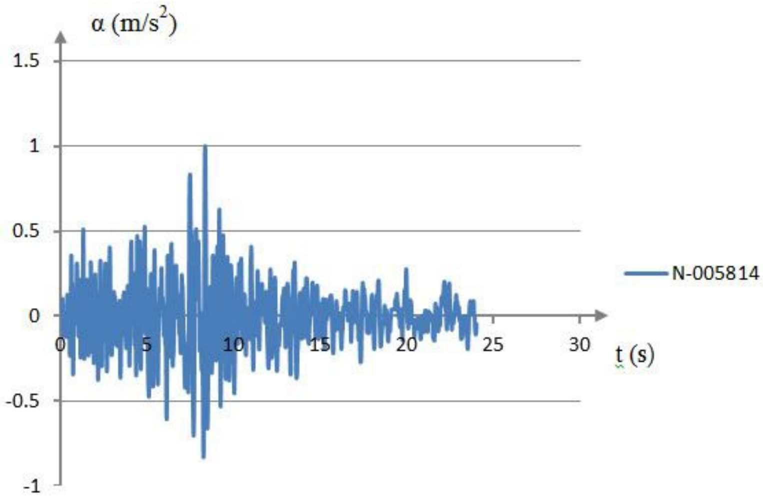


Fig. 5. Vertical normalized accelerogram of the Kalamata earthquake (code: 005814) (Drawing by the authors)

As a result of analysing vertical normalized accelerograms subjected to the 1997 Kalamata 6.4 magnitude earthquake of the superstructure, accelerations were obtained. The results were compared to the normalized accelerations, and it was determined how many times they were increased in the case of the real structure (Fig.6).

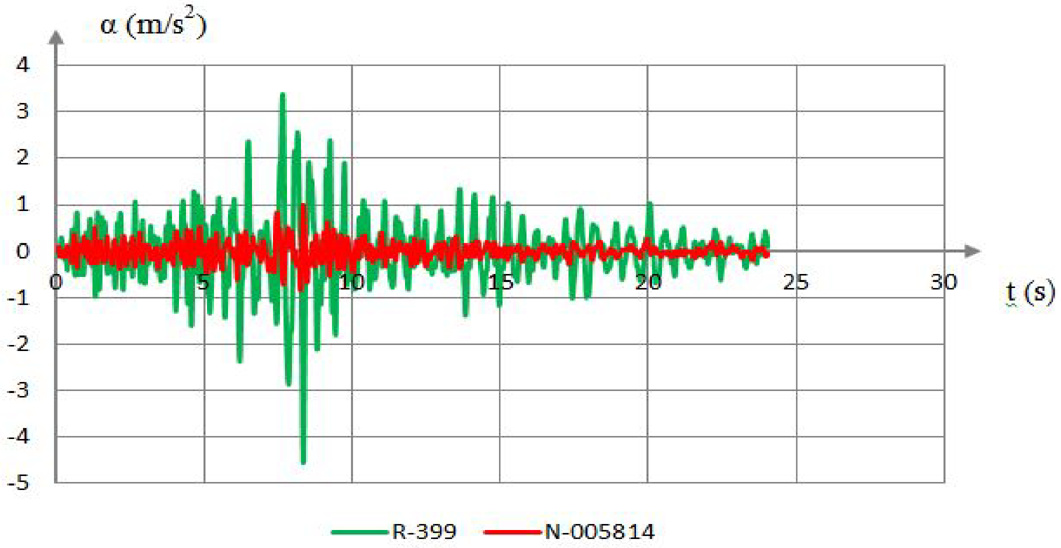


Fig. 6. Vertical normalized accelerogram (code:005814) and response of the superstructure with a scheme L=3x63.0 m under the impact of the Kalamata earthquake (Drawing by the authors)

For this specific case, the maximum acceleration of the response of the superstructure was 4.53 m/s2. Their spectra were constructed accordingly and are presented in Fig. 7.

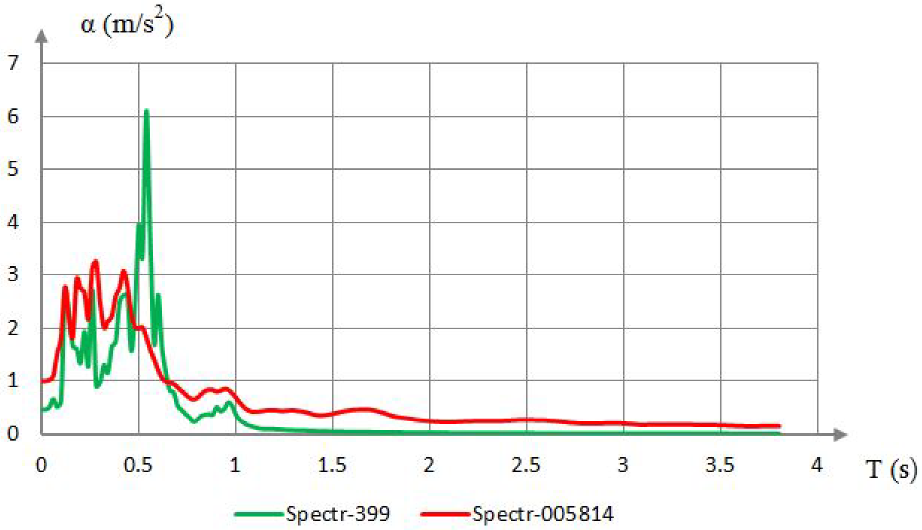


Fig. 7. The vertical normalized spectrum of the Kalamata earthquake (code: 005814) and the response spectrum of the superstructure with a scheme L=3x63.0 m (Drawing by the authors)

The same approach was applied to the rest of the selected accelerograms, which allowed working out the accelerations spectra (Fig.8).

Spectra of accelerations for soils of category I in terms of seismicity are given in Fig. 8, which includes the spectra provided by normative documentation (Geo [4], SNiP [5] [6] [7], EN [8] [9] and AASHTO [10]).

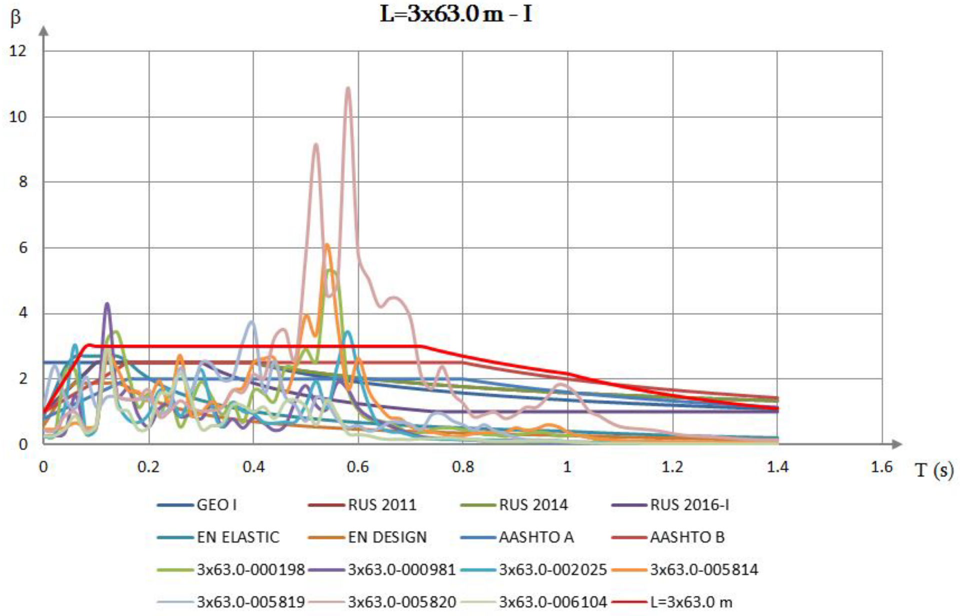


Fig. 8. Response spectra of the superstructure with a scheme L=3x63.0 m for soils of category I (Drawing by the authors)

The same approach was implemented for soil categories II and III during the construction of composite steel and concrete continuous span superstructure with a scheme L=3x63.0 m. Seven accelerograms were selected, and the spectra of accelerations were obtained as results of their impact. They are shown along with the spectra provided by different normative documents (GEO [4], SNiP [5] [6] [7], EN [8] [9] and AASHTO [10]) in Fig. 9 and Fig. 10.

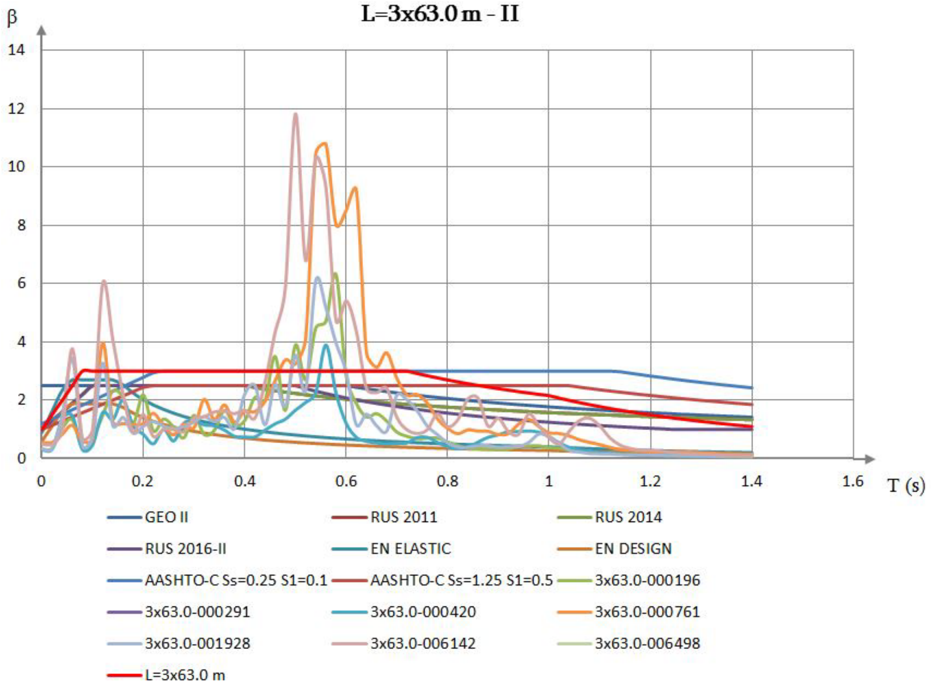


Fig. 9. Response spectra of the superstructure for soils of category II (Drawing by the authors)

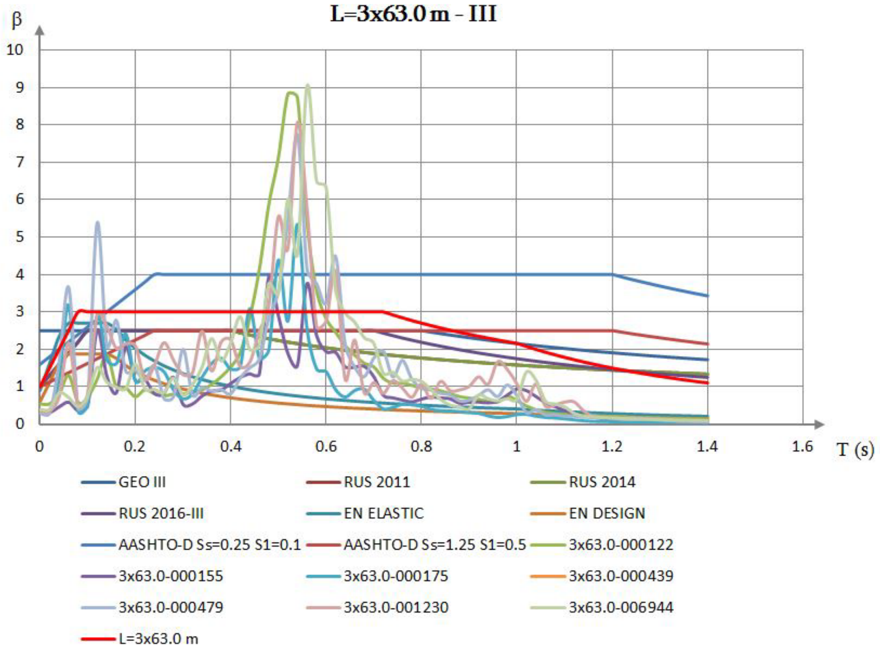


Fig. 10. Response spectra of the superstructure for soils of category III (Drawing by the authors)

The calculation of the selected superstructure was carried out with the spectra obtained by us for the soils of different categories, as well as with the methodology provided by different normative documents (GEO [4], SNiP [5] [6] [7], EN [8] [9] and AASHTO [10]).

3. RESULTS

The vertical component of the seismic action shall be represented by an elastic response spectrum Sve(T), derived using expressions [8]:

$$0 < T < T_B : S_{ve}(T) = a_{vg} \cdot \left[1 + \frac{T}{T_B} \cdot (\eta \cdot 3.0 - 1)\right]$$

$$T_B < T < T_C : S_{ve}(T) = a_{vg} \cdot \eta \cdot 3$$

$$T_C < T < T_D : S_{ve}(T) = a_{vg} \cdot \eta \cdot 3.0 \cdot \left[\frac{T_C}{T}\right]$$

$$T_D < T < 4\,s : S_{ve}(T) = a_{vg} \cdot \eta \cdot 3.0 \cdot \left[\frac{T_C \cdot T_D}{T^2}\right] \qquad (1)$$

where

$S_{ve}(T)$ – is the vertical elastic response spectrum;

T – is the vibration period of a linear single-degree-of-freedom system;

a_{vg} – is the design ground acceleration;

$T_B = 0.08$ – is the lower limit of the period of the constant spectral acceleration branch;

$T_C = 0.72$ – is the upper limit of the period of the constant spectral acceleration branch;

$T_D = 1.0$ – is the value defining the beginning of the constant displacement response range of the spectrum;

η=1 – is the damping correction factor with a reference value of η=1 for 5% viscous damping.

$$0 < T < 0.08 : S_{ve}(T) = 1 \cdot \left[1 + \frac{T}{0.08} \cdot (1 \cdot 3.0 - 1)\right]$$

$$0.08 < T < 0.72 : S_{ve}(T) = 1 \cdot 1 \cdot 3$$

$$0.72 < T < 1 : S_{ve}(T) = 1 \cdot 1 \cdot 3.0 \cdot \left[\frac{0.72}{T}\right]$$

$$1.0 < T < 4\,s : S_{ve}(T) = 1 \cdot 1 \cdot 3.0 \cdot \left[\frac{0.72 \cdot 1.0}{T^2}\right] \qquad (2)$$

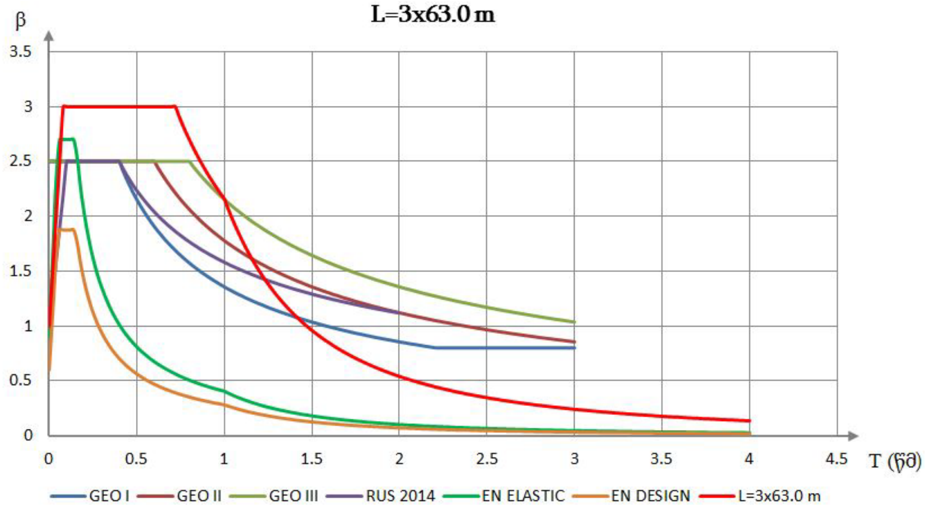


Fig. 11. Vertical response spectra of the superstructure with a scheme L=3x63.0 m (Drawing by the authors)

For the superstructure with a scheme L=3x63.0 m, calculations were made for all three soil categories at different levels. The results of seismic forces are presented in Table 2.

Table2 seismic forces of superstructure with a scheme L=3x63.0 m by different normative documents

Superstructure with a scheme L=3x63.0 m								
N	Name	Static	7 Intensity		8 Intensity		9 Intensity	
		M, t•m	M, t•m	%	M, t•m	%	M, t•m	%
1	L=3x63.0	2552.39	317.21	12.4	634.63	24.9	1271.65	49.8
2	GEO-I		105.94	4.2	254.57	10.0	551.82	21.6
3	GEO-II		131.96	5.2	264.13	10.3	528.49	20.7
4	GEO-III		136.08	5.3	217.86	8.5	408.69	16.0
5	RUS-2011		113.23	4.4	226.68	8.9	453.59	17.8
6	RUS-2014		119.71	4.7	239.65	9.4	479.52	18.8
7	RUS-2016-I		102.84	4.0	205.9	8.1	412.02	16.1
8	RUS-2016-II		165.12	6.5	330.47	12.9	661.39	25.9
9	RUS-2016-III		186.53	7.3	373.27	14.6	746.85	29.3
10	EN ELASTIC		309.47	12.1	619.16	24.3	1238.54	48.5
11	EN DESIGN		171.86	6.7	343.88	13.5	687.98	27.0
12	AASHTO-A		427.29	16.7	855.86	33.5	1715.01	67.2
13	AASHTO-B		534.16	20.9	1070.65	41.9	2144.59	84.0
14	AASHTO-C		884.32	34.6	1712.26	67.1	2952.4	115.7
15	AASHTO-D		1186.46	46.5	2069.35	81.1	3259.03	127.7

The graph presented in Fig. 11 was developed to visualize the results calculated on the basis of various normative documents (GEO [4], SNiP [5] [6] [7], EN [8] [9] and AASHTO [10]).

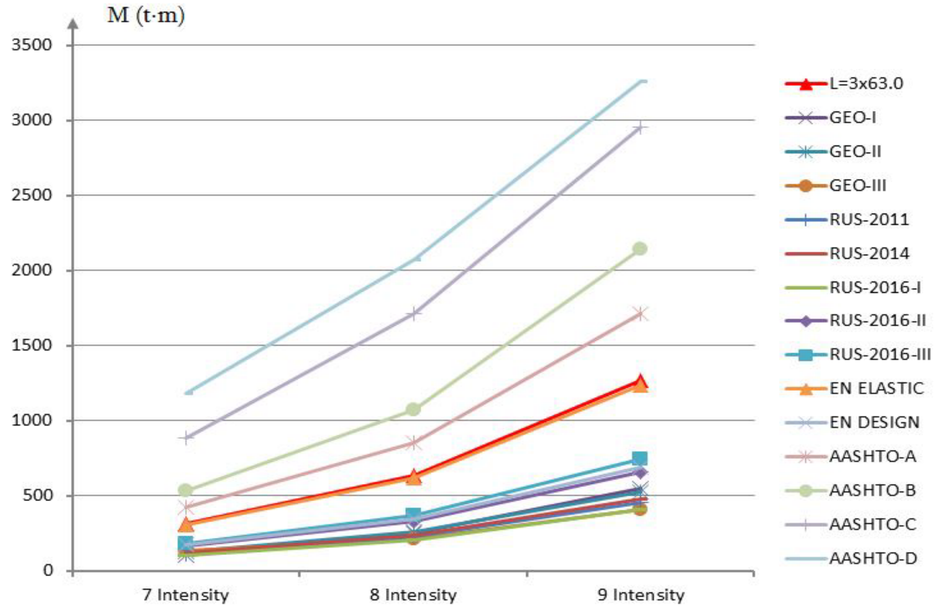


Fig. 11. According to various normative documents and new spectra, the values of the forces of the superstructure with a scheme L=3x63.0 m

Studies have shown that taking into account the first three modes of vibration of the superstructure with a scheme L=3x63.0 m, the magnitudes of the forces determined by the spectrum of the response obtained by the spectra given in the normative documents of (GEO [4] and SNiP [5] [6] [7]. The results also exceed the magnitude of the force received by the spectrum given in the normative documentation of EN [8] [9].

The vertical spectra given in different normative documents (GEO [4], SNiP [5] [6] [7] and AASHTO [10]) take into account different soil categories obtained by transforming the horizontal spectrum. The vertical spectrum is given only in the normative document of EN, and it does not depend on the soil category, which was also confirmed in this research - regardless of different soil categories, the range of the new spectrum obtained on the basis of the response spectra of accelerograms is unchanged. Therefore, it is possible to use one vertical response spectrum for all soil categories.

4. CONCLUSION

The spectra obtained by the impact of accelerograms on the composite steel and concrete continuous span superstructure with a scheme L=3x63.0 m produce significantly higher force values than the spectra obtained without taking into account their own fundamental periods.

As provided in the EN normative document, the following research confirmed that it is possible to use the same vertical response spectrum for all soil categories.

Studies have shown that it is necessary to use wide-area spectra for the long period composite steel and concrete continuous span superstructure with a scheme L=3x63.0 m.

5. ACKNOWLEDGEMENTS

This research PHDF – 22-1040 has been supported by Shota Rustaveli National Science Foundation of Georgia (SRNSFG).

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I graduated from the Georgian Polytechnic Institute with a degree in Railway Engineer-Builder In 1979. From 1979 to 1988, I worked as the head of the track distance at the Tbilisi Metro Rail and Ferns Service. I have been teaching since 1982. I am a Doctor of science (engineering). I have been a professor since 2006, and since 2016 I have been the Head of the Road Department of the Georgian Technical University. Since 2004, I have been engaged in expert work in the railway section. I have published 85 scientific articles, one monograph, 14 textbooks and methodological references.

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I was born on December 17, 1968. In 1993 I graduated from the Georgian Technical University with honours, specializing in bridges and transport tunnels. In the same year, I started working as a laboratory assistant in the Department of Bridges and Tunnels at the same university. I am a Doctor of science (engineering). Over the years I have worked in the same department as a Senior Laboratory Assistant (1994–2000), Seismic Laboratory Manager (2000-2001), Department Assistant (2001–2006), Assistant Professor (2006–2013) and Associate Professor (2013–2017). Since 2017, I have been working as a Professor of Bridging at GTU Road Department. I am the co-author of three inventions. I have published 24 scientific papers.

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ОДРЕЂИВАЊЕ СПЕКТРА ОДЗИВА СУПЕРСТРУКТУРЕ ДУЖИНЕ L=3x63,0 M

САЖЕТАК: Приликом сеизмичког удара, главни нагласак је стављен на оштећења стубова моста који су изоловани од хоризонталног детектора земљотреса. У складу с тим, при прорачуну мостова, реакциони спектри добијени са хоризонталног детектора земљотреса се користе и за стубове и за надградњу. Сеизмичка отпорност мостова је веома важна, посебно за надградње са великим распонима. Неопходно је конструисати динамичке криве сеизмичке отпорности за надградње одређеног система. У раду је обрађена композитна челично-бетонска непрекидна распонска надградња са шемом L=3x63,0 m, на којој смо директном динамичком методом извршили седам реалних земљотреса за све три категорије тла и изградили референтне спектре одзива. На основу добијеног спектра одзива и методологије предвиђене различитим нормативним документима, извршен је прорачун одабране надградње и одређене вриједности сила. Дискусија: На основу добијених резултата са референтним спектрима одзива и кривих датих у нормативној документацији, уцртани су графикони и одређена композитна челична и бетонска непрекидна распонска надградња са шемом L=3x63,0 m вертикалног спектра одзива.

Кључне ријечи: *фреквенција надградње, период, вертикални спектар одзива*