Journal of Civil Engineering and Architecture 17 (2023) 1-11
doi: 10.17265/1934-7359/2023.01.001

Structural Capacity Assessment of Cultural Bridges Key Study Dragoti Bridge

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Abstract: In this presentation, we have shown the methodology for the structural assessment of bridges that belong to the inventory of cultural heritage. Due to the significant number of "sub-standard" bridges, it is impossible for interventions in these bridges to be simultaneous and immediate, so certain criteria and priorities must be established in the ways of interventions for their rehabilitation. Bridges that are most at risk and need to be rehabilitated as soon as possible should be determined, and bridges that can be rehabilitated at a later stage should be identified. The prioritization scheme should include a number of aspects beyond the "pure engineering" ones. Main in this process are: seismicity of the area and the probability of the seismic event, vulnerability of the structure. Different structural systems may be considered to be more vulnerable in the event of an earthquake than others, and therefore may need attention as soon as possible. To make this preliminary assessment, we used the methodology of the US Highway Federation, then we proceed with the in-depth assessment of the carrying capacity using the well-known "time history" or "push over" methods, according to the specific case. As an example for the application of this methodology, we have taken the Dragoti Bridge, a category II cultural monument, the bridge with the largest span of light in Albania of 108 m.

Key words: Dragoti Bridge, structural rehabilitation, structural assessment.

1. Introduction

In the summer of 1923, the French senator Justin Godart visited Albania accompanied by a representative of the well-known French company "Five-Lille" specialized in the construction of bridges. Sejfi Vllamasi, in his memoirs, writes that during this visit he was asked by the representative of the French company to obtain the right to build the main bridges of Albania, which was a necessity for the time for the fact that the country had many problems with traffic. "The main bridges would be built of steel, starting from the Shijak Bridge". The government granted this right to the French company, as it has been a world-renowned specialized bridge company. The project for the construction of the Dragoti bridge, part of the agreement in September of the same year, between the Albanian government and the company "Five-Lille", an agreement which was not realized made this project after the treatment of several variants [1] in the years 1934-1935 to be realized by Ing. Confatonier of the Italian studio ANSALDO s.a. The superstructure of the bridge is a simple truss system of steel with passage from below. The choice of such a system depends on many factors, but the main one is the coverage of a large space as well as the impossibility of building on the downstream side as this could obstruct the flow of the river, for which full section beams become heavy and difficult to establish.

The substructure is reinforced concrete (abutment) and its connection to the superstructure is realizes by hinges. The length of the bridge is L = 110 m and its width is 7.5 m.

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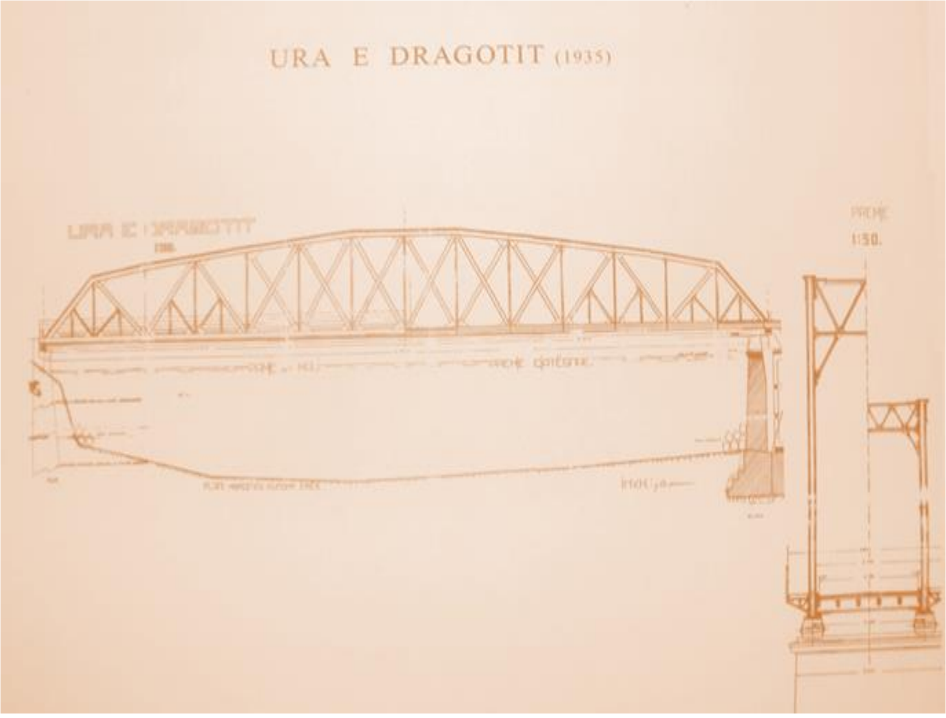


Fig. 1 Bridge front view designed in 1934.

2. Methodology

In the “Seismic Retrofitting Manual for Highway Structures. Part 1, Bridges” [2], two basic methods are presented for the preliminary assessment of bridges regarding their expected performance in a seismic situation, in order to set priorities for their rehabilitation: Indices Method (FHWA, 1995); and Expected Damage; Among the above two methods, the evaluation method through indices will be used more in this topic, as a simpler and faster method. The preliminary assessment does not mean the assessment of direct economic losses only, whereas such can be taken as the costs of repairing or replacing a damaged bridge. These losses do not include the so-called indirect socio-economic costs or expenses, which can be very important and often exceed the direct costs. Indirect costs include loss of life, injuries, business disruptions, delays due to traffic jams, etc. Estimating these costs is a complex problem and is subject to probabilistic methods related to the seismic event.

Before going into details about the seismic rehabilitation of bridges, a general classification of them in SRC (seismic rehabilitation category) is made. In summary, the steps followed for determining the SRC of a bridge are given below:

Step I: The importance of the bridge is determined, which can be “standard” or “essential”. After this depending on the years remaining from the design life of the bridge, the classification is made in ASL (anticipated service life) category lifespan levels:

0-15 years: ASL 1
16-50 years: ASL 2
over 50 years: ASL 3

Finally, the classification of the geotechnical conditions in the categories of the site is made (referred to the American standards, this classification is A-F, while according to the Eurocodes A-E and S1-S2) [3].

Step II: Depending on the importance of the bridge and the remaining life, the classification is made in “performance level” (PL0 through PL3), based on the anticipated service life and bridge importance (Table 1).

Step III: This step consists in the calculation of the seismic risk, expressed in the value “SHL (seismic hazard level)” in function of SD1.

Table 1 Performance scale.

Standard bridge		Important bridge for transportation	
ASL 1	PL 0	ASL 1	PL 0
ASL 2	PL 1	ASL 2	PL 1
ALS 3	PL 1	ALS 3	PL 2
ALS 3	PL 1	ALS 3	PL 2

Table 2 Seismic hazard level.

Hazard level	SD1 = FVS1	
I	from 0	up to 0.15
II	from 0.15	up to 0.25
III	from 0.25	up to 0.4
IV	above 0.4	

Table 3 SRC calculation table depending on SHL and PL.

SHL	PL	SRC
	PL 0	A
I	PL 1	A
	PL 2	B
	PL 0	A
II	PL 1	B
	PL 2	B
	PL 0	A
III	PL 1	B
	PL 2	C
	PL 0	A
IV	PL 1	C
	PL 2	D

As mentioned above, in order to set priorities for the rehabilitation of bridges, vulnerability, seismic and geotechnical risks, as well as socio-economic factors that affect the importance of the bridge must be taken into account. This is achieved, by first making independent rankings (classifications) of bridges related to structural problems and secondly by considering non-structural factors, in order to reach a clear conclusion about the priorities related to the rehabilitation of bridges.

Thus, the classification or assessment system is both quantitative and qualitative. The quantitative part produces a seismic rating ("bridge rank", R) based on structural vulnerability and site hazard. The qualitative part modifies the rank in a subjective way that accounts for importance, network redundancy, non-seismic deficiencies, remaining useful life, and similar issues to arrive at an overall priority index. This leads to a "priority index", P: P = f (R, importance, non-seismic situations, other factors...).

Bridge ranking "R" would depend on vulnerability (V) and seismic hazard (E). Each of these factors takes values from 0 to 10 and their product gives the bridge's rank:

$$R = V \times E \tag{1}$$

Therefore, R can vary from 0 to 100, and the higher the score, the greater the need for the bridge to be retrofitted (ignoring at this time the other factors).

2.1 Vulnerability Rating (V)

Although the overall performance of the bridge depends on the best possible interaction between the constituent components, some of them are more vulnerable than others, such as bearings, connections and seats, piers, columns and foundations, abutments and soils.

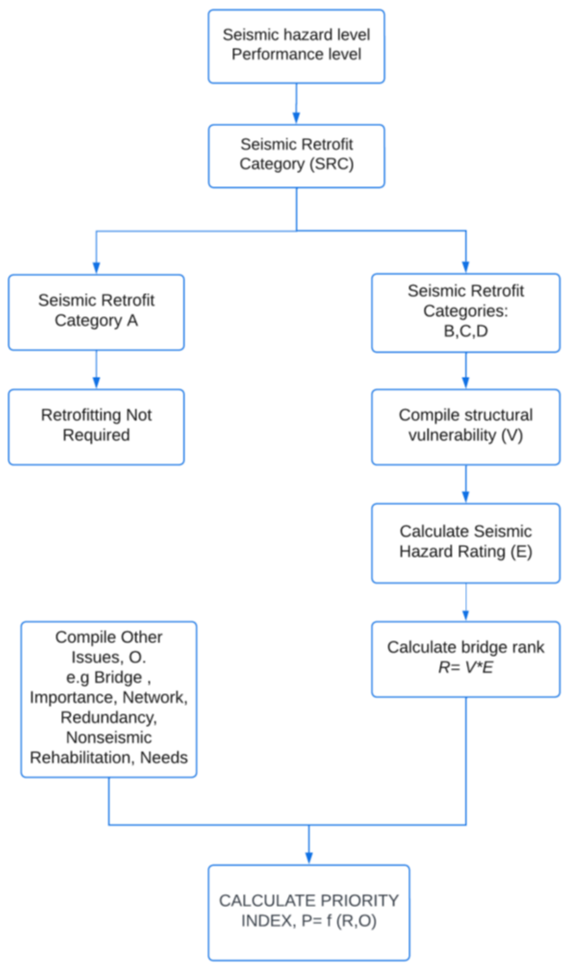


Fig. 2 Seismic rating method using indices.

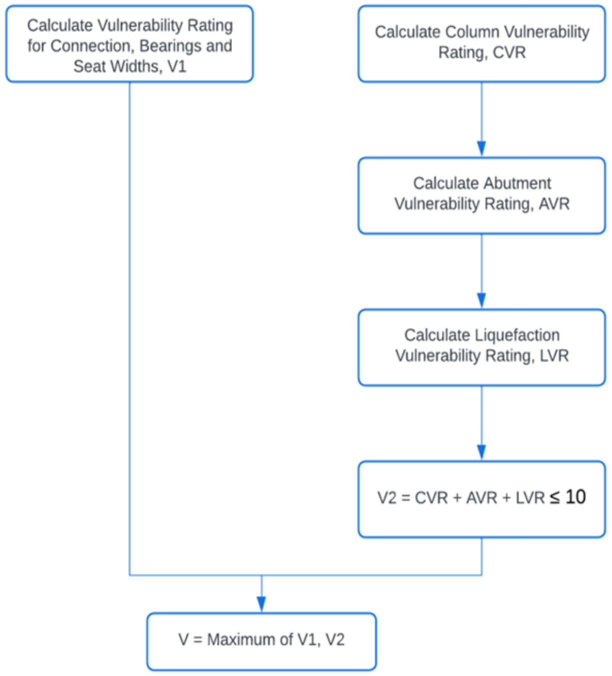


Fig. 3 Calculation of bridge vulnerability, V.2.

Of the above elements, insufficient hinges, connections and supports are among the most common problems in bridges but on the other hand they are the least expensive. Therefore, their vulnerability is calculated separately from the rest of the structure and is marked V1. The vulnerability of the remaining elements is defined as the sum of the rating of each element that are susceptible to failure noted V2. The overall vulnerability assessment is taken as the largest between V1 and V2 and is summarized in Fig. 3.

The comparison between vulnerability V1 and V2 serves to get an indication of which remediation method needs to be used. If the vulnerability rating for the bearings is equal to or less than the vulnerability rating of other components, simple retrofitting of only the bearings may be of little value. Conversely, if the bearing rating is greater, then benefits may be obtained by retrofitting only the bearings.

3. Description of the Bridge

The superstructure consists of two trusses with a span of 108 m and a maximum height of 12 m, with a passage from below and a polygonal upper chord. The upper belt of the truss has a polygonal shape due to the large span and this way a more uniform distribution of stresses is ensured in both chords [4].

The grid of the truss is with the triangular system (diagonals) as well as with additional vertical bracing located every 6.75 m. These additional vertical elements connecting to the upper chord reduce the free length of the chord working in compression, when transferring to the lower chord they serve to reduce the length of the panels of the passing part. As a bridge with a large span, other additional elements are added to the truss network, which are the webs. The braces are located below and their help consists in distributing the stresses as uniformly as possible in the lower chord as well as reducing the free length of the panels of the passing part. The interaxle between the two trusses is 5.43 m, this is in function of the moving vehicles and the construction of the passing part. Sidewalks with a width of 1 m come out of the trusses in the form of a cantilever. The construction of the overpass is a structure composed of road layers, metal panels, longitudinal beams and transverse beams. The road layer has an average thickness of 20 cm, consisting of gravel and bituminous material. Under this layer, the metal panels are placed every 18 cm and with a length of 75 cm, supported on the longitudinal beams. The longitudinal beams have a length of 3.375 m and are placed on the transverse beams

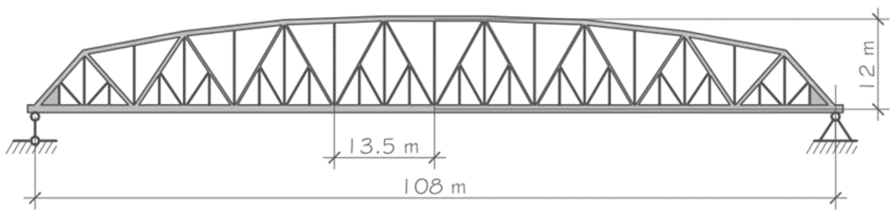


Fig. 4 Schematic front view.

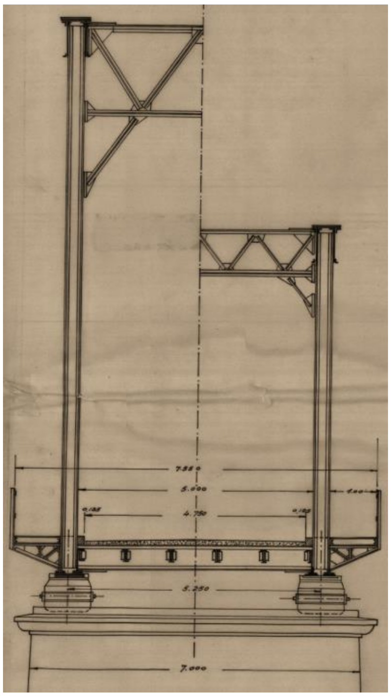


Fig. 5 Schematic bridge cross section.

at an interaction distance of 0.75 m. Their function is to transmit the load they receive from the transmission line onto the transverse beams. The transverse beams transmit the load they receive from the longitudinal beams to the trusses. They have a length of 5.0 m and are located every 3.375 m.

In order to maintain the transverse stability, the shape in space and the rigidity of the superstructure, the trusses are connected to each other with a system of longitudinal connections in the upper and lower chord. Another function of these connections is the transmission of horizontal wind forces, transverse shocks coming from mobile loads, to the supports of the trusses. Connections also participate in load distribution, when only one side is loaded with vertical load. The cross-section of truss elements consists of metal plates and profiles. The truss belts have a composite cross-section asymmetric against the horizontal axis. The lower belt consists of 2 separate vertical walls, each connected by 2 profiles and metal plates from below. To help the joint work of these 2 "split beams", along their length at the lower level, they are joined with horizontal plates at a certain step. The upper chord consists of 2 vertical walls, each connected by 2 profiles and joined by metal plates placed from above, giving the section the shape of the letter "U" inverted. Depending on the stresses, the change in the area of the cross-section of the bands is realized by changing the number and thickness of the section of the metal plates, thus not changing the width of the element. The truss mesh elements have a cross-section consisting of double "U" profiles that are connected to each other with horizontal plates, maintaining a distance between the two branches of the elements that corresponds to the width of the truss bands. The cross-section of the connection elements consists of 2 separate profiles connected along the length with connecting plates.

4. Preliminary Assessment of Dragoti Bridge

Assessment of the bridge will be made in relation to the needs for its structural rehabilitation.

Determine the SRC for the Dragoti bridge.

Step I: Based on the year of construction of the bridge, it can be said that the level of remaining life of this bridge is ASL1 (i.e., 0-15 years).

According to the geological and geotechnical conditions of the terrain, the bridge can be classified in category "A" according to Eurocodes (rock foundation) and "B" according to AASHTO.

Step II: From the results of the first step, it can be said that the expected performance level for this bridge is PL 0, so a minimum performance is not required for the bridge even though it can be considered important from a cultural and historical point of view.

Step III. The seismic risk for the bridge construction area is taken from the study "Seismicity, Seismotectonic and Seismic Risk Assessment in Albania" [5]. The maximum reference acceleration of the ground is agR = 0.241g. In order to calculate SD1 the following reasonings are applied:

SD1 is the spectral value for T = 1 s, which includes geotechnical effects, for an earthquake return period of 1,000 years. The agR must be corrected for a return period of 1,000 years.

ag = γI agR = (TLR/TL)-1/k agR = (475/1,000)-1/3 0.241g = 0.309g

The spectral value for T = 1 s, is:

SD1 = Se(T = 1) = ag S η 2.5 (TC/T) = 0.309g × 1 × 1 × 2.5 × (0.4/1) = 0.309g (for spectrum of the first type, ground Type A according to Eurocodes).

SD1 = Se(T = 1) = ag S η 2.5 (TC/T) = 0.309g × 1 × 1 × 2.5 × (0.25/1) = 0.244g (for spectrum of the second type, ground Type A according to EN-1998-1).

For the purposes of this study, the spectrum of the first type will be used, which is more unfavorable for the Dragoti bridge. So, SD1 = 0.309g will be accepted.

For this seismic risk, relying on Table 2, the level of seismic risk will be accepted SHL III. Further, from Table 3 we get the classification of the bridge in SRC A seismic retrofit category.

As conclusion is reached that seismic rehabilitation is not recommended for the Dragoti bridge, and as explained above, the main reason for this conclusion is the long period of use of this bridge (ASL 1 category). However, based on other cultural and historical requirements, the rehabilitation of this bridge is necessary.

4.1 Modeling of the Existing Structure

The calculation model of the bridge was made in the CSI Sap2000 program. All the elements of the structure are designed and modeled as in the original project. The superstructure is a simple truss system with bottom passage. It consists of two trusses with a span of 108 m, an axial distance between the two trusses of 5.43 m and a maximum height of 12 m.

The connection to the substructure is made with rollers (on the Tepelena side) and hinges (on the Dragoti side). The fixed hingers have 3 degrees of freedom and ensures free rotation of the superstructure in all three directions. The rollers have 4 degrees of freedom, of which 3 ensure the free rotation of the superstructure in all three directions and one degree of freedom ensures the free displacement of the superstructure only in the longitudinal direction.

The passing part is modeled with shell elements, with thickness t = 25 cm and the material has a volume weight of γ = 26.2 kN/m^3.

Moving load is taken from load model N-13, and crowd load according to KTP-21-78 [6] and load model LM-1 according to EK 1991, Part 2 [7].

The wind load is taken with intensity as below:

In the presence of moving load the value is taken 0.5 kN/m^2 and the height of the vehicles line is 2.5 m, while in the absence of a moving load it is taken 1.80 kN/m^2 [6].

The seismic load is taken in accordance with EK 8, Part 1&2. For category of terrain "A", the reference acceleration is ag = 0.241g. The importance factor γ_I is assumed to be 1, as for ordinary bridges.

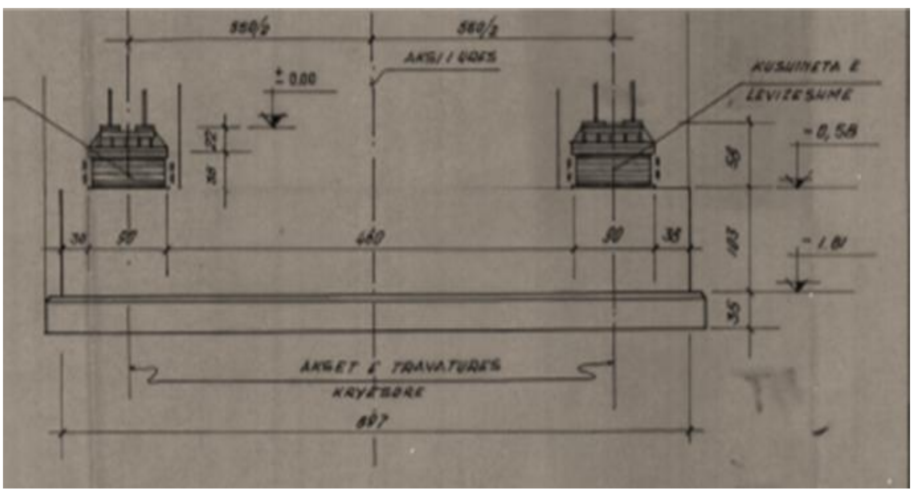
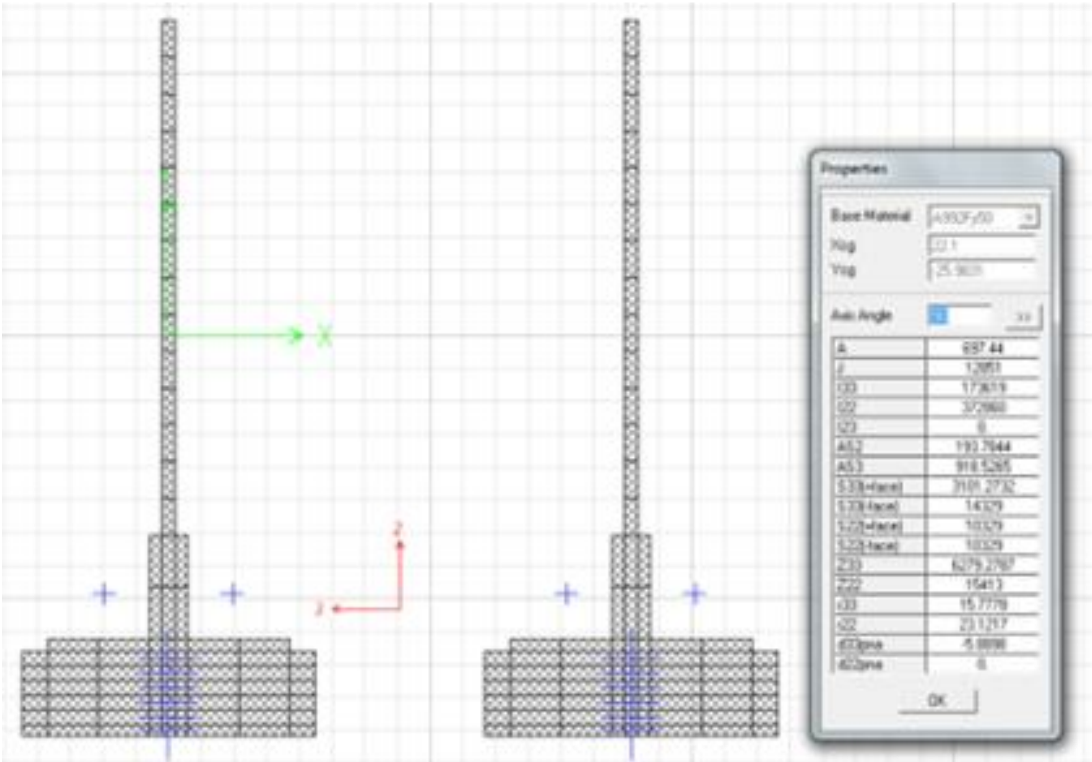
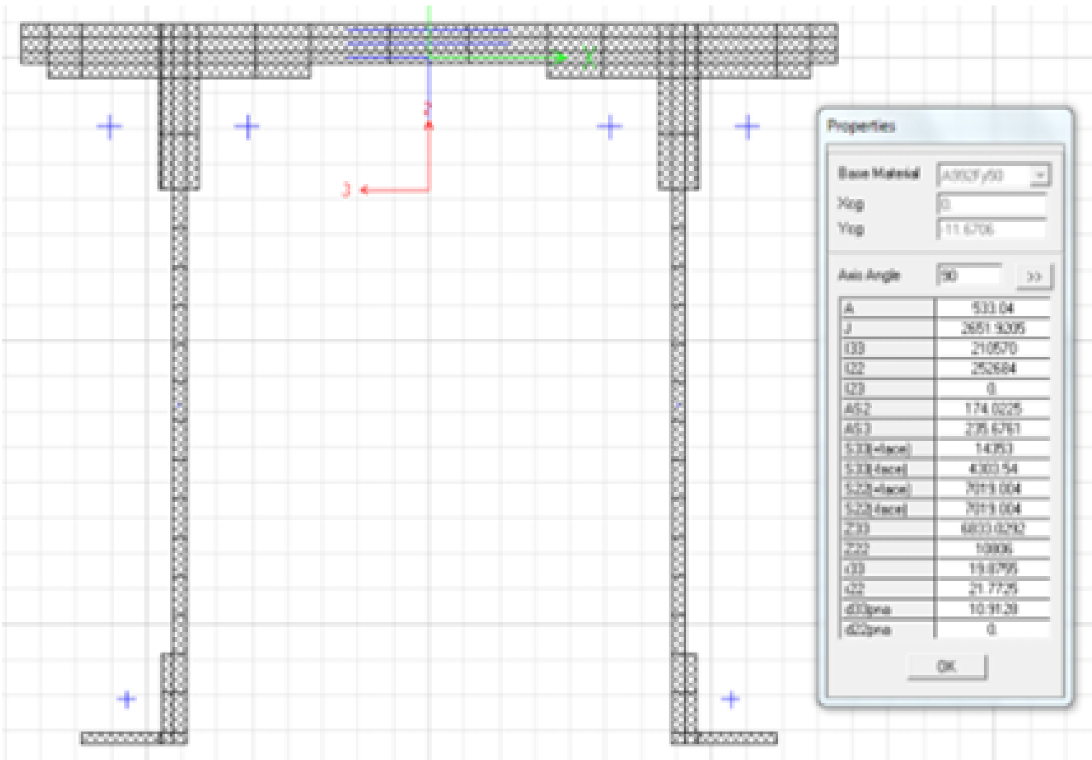


Fig. 6 Moveable hinges.



(a) mid cross-section of bottom chord



(b) mid cross-section of bottom chord

Fig. 7   Main truss sections.

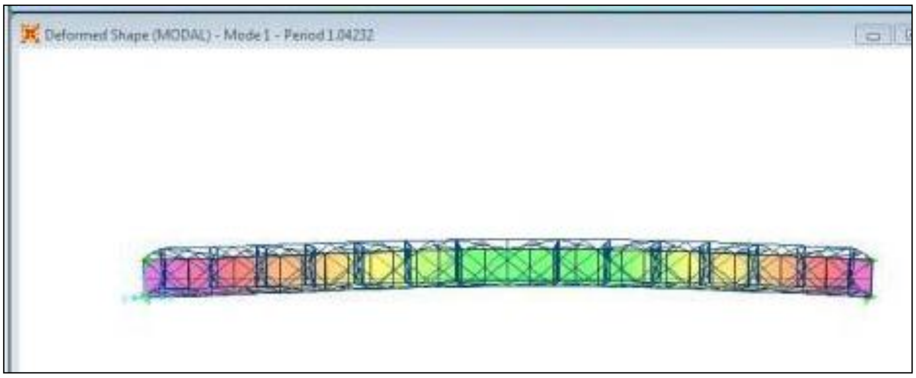


Fig. 8 The first mode of variation, *T* = 1.184 s.

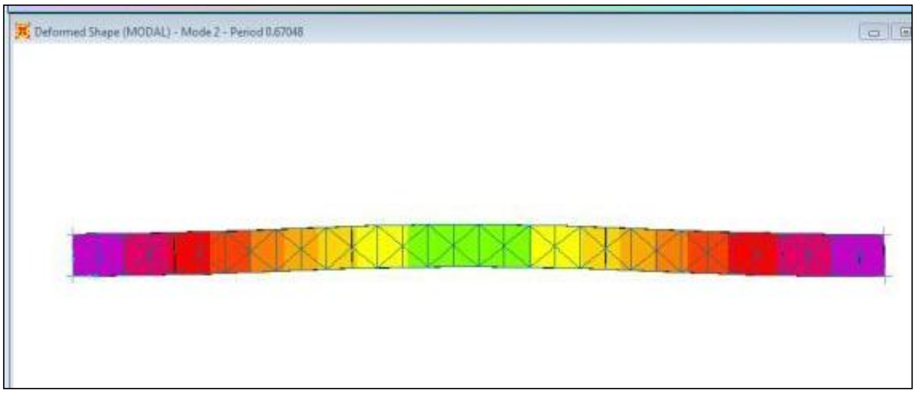


Fig. 9 The second mode of variation, *T* = 0.670 s.

Table 4 Periods for 5 first modes of bridge variations.

Form	Period (s)	Description
1	1.184	Translational motion in the transverse direction (half-wavelength form)
2	0.670	Rotational movement against the longitudinal axis of the bridge
3	0.6128	Translational movement of two central vertical elements of the truss, longitudinal direction
4	0.6124	Translational movement of two central vertical elements of the network, longitudinal direction
5	0.6085	Translational movement of a central vertical element of the truss, longitudinal direction

5. Analysis and Results

From spectral analysis results, the first and second modes of movement correspond to the transverse direction.

In summary, for the first five forms of oscillation, the main data are presented in Table4.

5.1 Analysis Results from Moving Loads Model N-13

From the analysis with moving loads, normal forces are derived for the most unfavorable position of the vehicle. For the base combination with this load, the results are shown in Fig. 10 below.

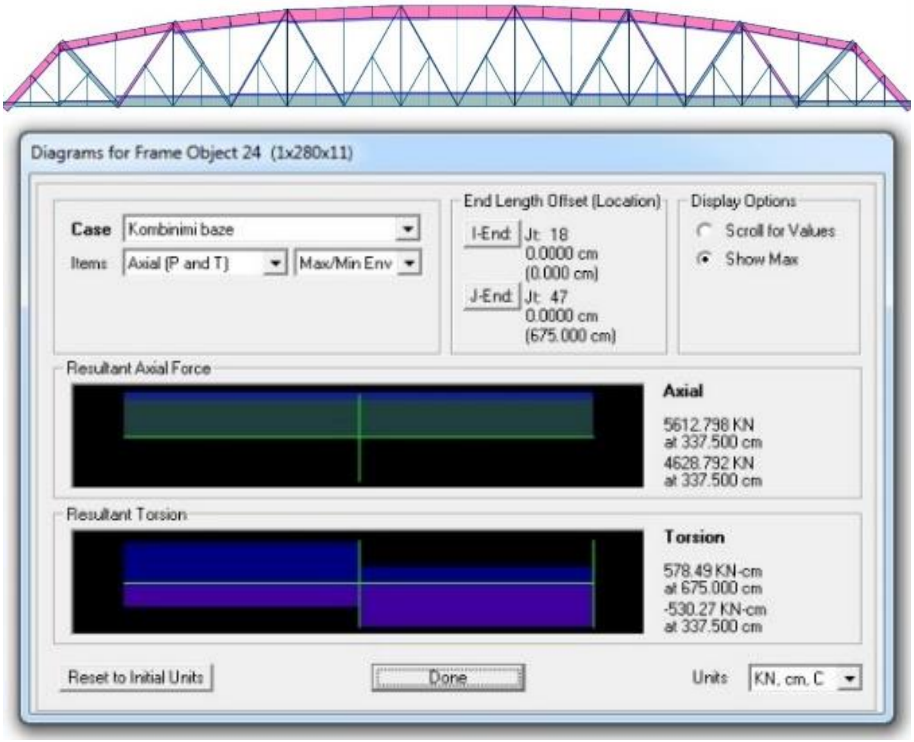
The maximum deflection in the middle of the space is 14.65 cm.

From this analysis, it shows that the bridge meets the conditions for passing the N-13 load, the basic combination according to KTP-21-78 [6].

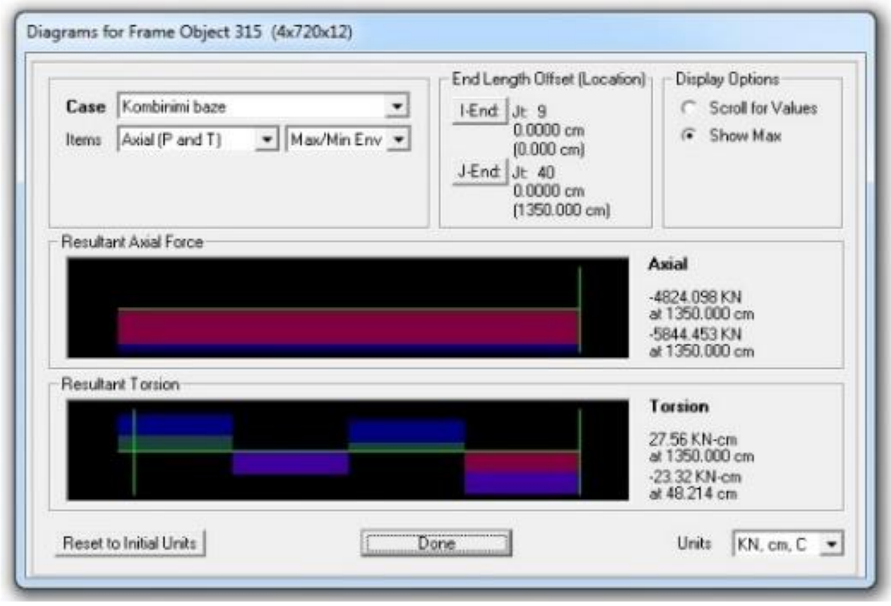
For the combination according to Eurocodes, as mentioned above, LM-1 and self-weight were taken into consideration. For this combination, the stresses in the elements exceed their resistance, so the structure does not meet the requirements of the Eurocodes for handling traffic loads.

5.2 Nonlinear Static "Pushover" Analysis

For the "pushover" analysis, the existing bridge model was used, making gradual loading according to the direction of gravity and monitoring the settlement of the mid-span node.



(a) mid cross-section of bottom chord



(b) mid cross-section of bottom chord

Fig. 10 Normal forces in mid cross sections.

Because of the "statically determinated" scheme, it is not expected that the pushover analysis will result in a capacity curve with a plastic phase, since the formation of the first plastic hinge turns the scheme into a mechanism. The plastic hinges here are modeled in tension and compression, adapting the working nature of the truss elements.

Thus, from its own weight, the bridge settles 10 cm, while at the moment of creating the "first" plastic hinge, the maximum settlement is 28.45 cm. After this moment, the capacity drops immediately after the mechanism is created.

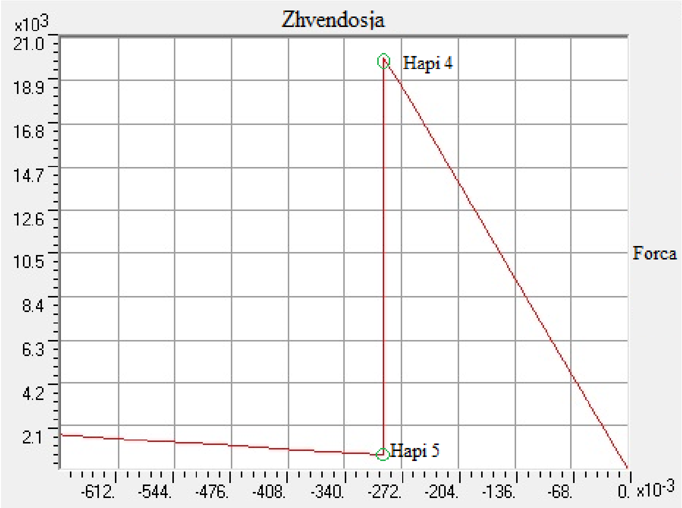


Fig. 11 Pushover curve for vertical loading.

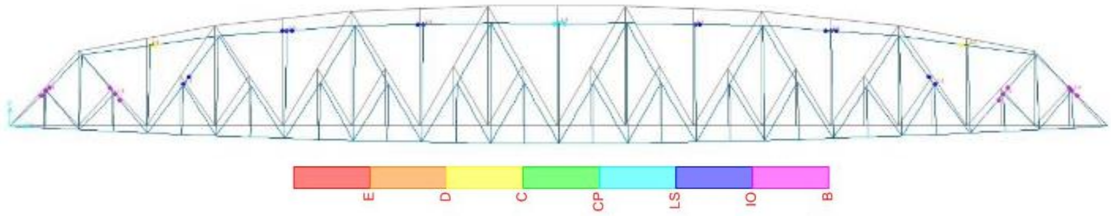


Fig. 12 Creation of the mechanism of destruction.

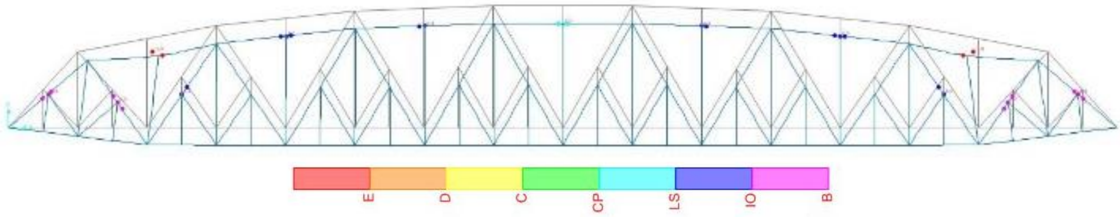


Fig. 13 Development of plastic hinges.

The fourth step of the analysis corresponds with the creation of the destruction mechanism. At this moment, plastic hinges are created on the elements of the upper chord and the diagonals near the supports.

The fifth step of the analysis shows the further development of the plastic hinges until the destruction of the elements

6. Conclusions

Albania has a significant number of bridges that belong to the inventory of cultural heritage, which from the point of view of design standards do not meet those of today's standards. The Dragoti Bridge, presented in this article, is representative of that part of bridges in Albania that were designed and built in the first half of the 20th century, and that are of particular cultural and historical importance. Following the steps presented in this presentation for the preliminary assessment of bridges, it was concluded that:

(1) The preliminary assessment of Dragoti Bridge showed that a detailed study for rehabilitation is not required, because it has almost fulfilled its design life. However, the bridge's functionality and historical values must be preserved.

(2) In order to preserve its historical values, in addition to the measures (cleaning, painting, replacement of

some elements of the same size), since it does not meet the requirements for normal use with today's traffic loads, it is recommended to build a new one, next to the existing bridge, as the best solution.

(3) This method should include other models and bridges in our country because many bridges were designed and built years ago and must be calculated with the new codes and must be built with new technology.

(4) For all existing bridges, a preliminary assessment must be carried out to determine the sequence of their rehabilitation process.

References

[1] Vllamasi, S. 2000. *Political Encounters in Albania (1897-1942) Memories and Historical Assessments.* Neraida: Publishing House Neraida. ISBN: 9992771313.

[2] Buckle, I., Friedland, I., Mander, J., Martin, G., Nutt, R., and Power, M. 2006. *Seismic Retrofitting Manual for Highway Structures: Part 1—Bridges.* New York: US Department of Transportation-Federal Highway Administration.

[3] CEN (Comité Européen de Normalisation) Draft SSH EN 1998-1. "Design of Structures for Earthquake Resistance—Part 1: General Rules, Seismic Actions and Rules for Buildings." 2004; Draft SSH EN 1998-2: Bridges, 2005.

[4] Central Technical Archive of Construction (AQTN).

[5] Academy of Sciences of Albania. 2010. *Seismicity, Seismotectonic and Seismic Risk Assessment in Albania*. Tirana, Albania: Academy of Sciences of Albania.

[6] Albanian Technical Design Conditions Concrete and Reinforced Concrete Bridges and Culverts on the Highways, KTP-23-78, Annexes 3, p. 61.

[7] CEN (Comité Européen de Normalisation)-EN 1991-2—Actions on Structures—Part 2: Traffic Loads on Bridges, 2003.