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Recent Structural Set and Load Test of Simply Supported Pernica Bridge

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ABSTRACT. Some structures and their relationships, positions in space and shifts represent the structural set of an area, as included within regional units, and smaller or larger portions of the earth's crust known as the Earth's plates and micro plates. The most important fact is that tectonic movements are always possible around the locations of considered bridges. Therefore, it is certainly necessary to define in detail their characteristics due to the potential impacts on individual bridges. A recent structural set was made for the Pernica bridge. To assess the bridge in micro sense the load test of the bridge was performed.

Keywords: load test, recent structural set, strain gauge, inductive transducer, accelerometer, bridge surveying, DASR method.

1. Introduction

Geodetic measurements are of great importance during the construction of a bridge. Geodetic plans are made based on geodetic measurements. Geodetic plans of different scales must be made for the purpose of building a bridge. Studies for the location of a bridge are made on small scale maps in which, amongst other tests includes the development of the recent structural set area where the bridge is planned for construction. Furthermore, special geodetic plans of larger scales should be obtained when designing the bridge.

During the bridges construction a precise geodetic control measurements must be conducted. In order to measure the actual state of the constructed object (for technical inspection), measurements are carried out after the construction of the bridge.

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In addition surveys of the bridge carrier construction should also be performed. After the construction of the bridge, when the bridge is at the exploitation phase, geodetic measurements are performed at bridge load test in order to monitor the behavior of the bridge (determination of displacements and deformations). *However, it may happen that bridge collapses the next day after the load stress test finds no structure micro defects, due to other extreme external influences.* Therefore, it is good to investigate the bridge also in macro level and make the recent structural set.

The positions of the Pernica bridge in relation to the assessments of recent tectonic movements that can be expected at the bridge location was analyzed. Data are obtained that significantly affect the stabilities and possible deformations of the bridge.

Load testing of bridges is usually performed for structural health monitoring, diagnostics, damage detection, load-rating, condition assessments, load carrying capacity estimation and model updating (Ataei et al. 2005). Determining the vertical displacements and deformations of structural elements is carried out during construction in order to control the system and after construction for the purpose of monitoring and evaluating reliability after a certain time of usage. There are several different methods for performing test loads on bridges but, in general, it involves the placement of sensors on all critical load carrying members and electronic measurements of their individual responses as known vehicles traverse the bridge (Chowdhury and Ray 2003). The method used depends on the type of construction, accessibility, required accuracies, sensitivities and reliabilities of the used instruments. During scientific research, the newest methods are often used for a link between the results, analysis methods and displaying the results, such as photogrammetry (Guarnieri et al. 2004, Albert et al. 2002, Jauregui et al. 2003, Maas and Hampel 2006) and laser scanning method (Gordon et al. 2004, Schäfer et al. 2004, Fuchs et al. 2004).

Yet the unavailability of certain parts during the constructions of bridges can be a serious problem. In practice classical surveying methods such as trigonometric methods and levelling are still used, and so are the latest measurement instruments. If possible, physical methods such as measuring with acceleration sensors, LVDT (Linear Variable Differential Transducers) (Sanli et al. 2000) and strain gauges (Vurpillot et al. 1996, Stone et al. 2001) should also be applied. Under extremely difficult field conditions (very large bridge spans and/or bridges passing over water or steep and deep valleys), it is necessary to simultaneously apply two or more independent methods (Knapp et al. 1998, Meng et al. 2007).

For testing the response of a bridge one of the possibilities is vibration analysis of individual structural elements. Studies on the vibrations of concrete and steel beams or bridges have been published (in several papers). Simply supported bridges have been tested and the results have been published in various articles such as (Dicleli and Bruneau 1995, Law et al. 1997). An example of vibration regarding railway bridges from dynamic loads is the article of Garinei and Risitano (2008). The response of the bridge to vehicle load was investigated by authors such as Law and Zhu (2004), Ashebo et al. (2007), O'Brien et al. (2009), Deng and Cai (2009).

New field investigations into the dynamic influences of vehicles or trains on bridge are presented in the papers by Deng and Cai (2009) and Xia et al. (2005).

To assess the Pernica bridge position in macro scale (for a purpose of safety assessment) a geology studies with recent structural set were made.

2. Geology studies

Tectonic movements continuously deform the Earth's surface. The amplitudes of the recent movement developments of any point on the surface can be determined by geodetic measurements. Older and also recent tectonic shifts are determined by field geological measurements in zones of tectonic faults. Therefore it is always required to compare the data obtained from geological and geodetic measurements. It is important to point out that the Earth's crust, including surface area, is presented with geological structure built from the rocks of different composition and density. Some structures and their relationships, positions in space and shifts represent a structural set of an area, which is included in regional units, and smaller or larger portions of the earth's crust known as the Earth's plates and micro plates. The most important fact is that the tectonic movements are always present around locations of considered bridges. Therefore, it is certainly necessary to define in detail their characteristics due to the potential impact on the individual bridge.

Identification of tectonic activity requires determination of the causes of tectonic activities in a regional area in the first place and then in narrow areas around the considered location. Elaboration of recent geological structural relationships was performed by the classification of structures and faults, the shifts in the parts of the structure in the side faults and particular the analysis of position of bridges in active structural set.

The necessary data on tectonic activity were collected with the help of previous information and knowledge from various published and important papers that point to the recent dynamics of the structural set around the considered location. First, the basic information about the rocks on the surface and structural relationships in the basic geological map sheets Maribor and Leibnitz (Žnidarčič and Mioč 1988) is chosen.

Further, important structural classification and data of structural relationships on the surface and in depth and position of the bridge considered in the broader context are presented (Anderson and Jackson 1987, Mantovani et al. 1992, Prelogović et al. 1999, Moores and Twiss 1999, Placer 1999, Castellarin and Cantelli 2000, Vrabec and Fodor 2004). Especially prominent works of seismotectonic relationships, stress regime and geodetic-geological data on recent tectonic movements (Ribarič 1983, Del Ben et al. 1991, Grünthal and Stormeyer 1992, Wells and Coppersmith 1994, Miškovič et al. 1998, Altiner 1999, Poljak et al. 2000, Pribičević 2001, Pribičević et al. 2002, 2003, 2007, Grenczy and Kenyeres 2006, Bada et al. 2006, Geodetski zavod Slovenije 2006, Đapo 2009, ARSO GURS 2011) are considered.

3. Recent geologic structural set and the tectonic activities for Pernica bridge

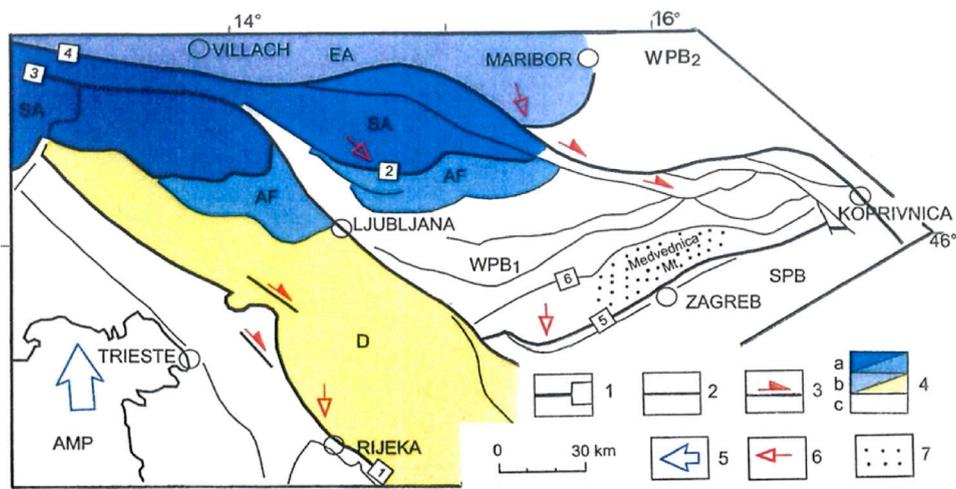
In order to collect necessary data about the location of bridges, a detailed structural-geological mapping was needed. Thus, the most important structural data on the dynamics of recent structural assembly was obtained and a series of outcrops of faults were discovered. Required measurements of structural elements,

which indicate the particular type, origin and location of faults in the structural part, conducted; and the side faults of the movement and the related stress and deformation structures were found. Strict regulations of position and the mutual relations of faults led to the study of further satellite images. The collected data emphasizes the determination of compression stress, its orientation and angle of the action. At each point of measurement the orientation of the local compression stress is determined. Such stress causes deformation of parts of the structures. The orientation of the maximum compression stress (emphasized in the attachments) is determined from several data. The maximum compression stress directly shows the basic structural relationships, in fact the positions and movements of the complex of rock walls of different densities form the structural set.

The first notable regional structural set (Fig. 1) is highlighted in the recent tectonic activity review. These regional structural units are present in Slovenia: Southern Alps (marked as SA) and Prealps (AF), Eastern Alps (EA), Dinarides (D), Adriatic microplate (AMP) and the western part of the Pannonian Basin, which includes the Sava fold (WPB1) and the Slovenian hills (WPB2). In these boundaries important structural set faults are extended: faults Gorica – Illyrian Bistrica – River (1), the fault of the Southern Alps (2 – eastern part known as the Sava fault), fault Fella – Save! – Sheffield (3), Periadriatic – Drava fault (4) and Zagreb fault (5). Initial tectonic movements that cause the structural set are shifts of the Adriatic microplate. They condition the extreme compression in the Southern Alps and northern Dinarides. Consequently, reversing structure and transcurrent right shifts of the Alps and Prealps units arises. The rotation of individual units results in shifts. The western boundary part of the Pannonian Basin is located partly in the wedged position between the Alps and the Dinarides. The result is transpression space. This means that tectonic movements conditioned the space compression with a general right tectonic transport.

At present recent tectonic activity directly indicates occurrence of an earthquake. The strongest earthquakes occur in the western part of the Southern Alps, in the northern part of the Dinarides and in the border region of the western and southern part of the Pannonian Basin. Throughout all Slovenia is a significant frequency of earthquakes. Earthquakes have also occurred around locations of considered bridge. However, the magnitude of the most earthquakes is up to 4.9. In our region, three epicentral areas with earthquakes of a great strength can be noticed (Ribarič 1983):

1. Ljubljana: A higher concentration of earthquakes located around Cerknica Lake, Litija and Ljubljana. The strongest earthquake of the intensity VIII – IX° of MCS scale and magnitude 6.4 occurred near Ljubljana in the year 1895.
2. Idrija: The strongest earthquake of the intensity X° of MCS scale and magnitude 6.9 occurred in the year 1511.
3. Furlanija: The strongest earthquake occurred in the year 1976 – the intensity IX – X° of MCS scale and magnitude 6.4. In the past there were seven very strong and devastating earthquakes. The strongest earthquake ever was in the 16th century with the estimated intensity of X° MCS scale and magnitude 7.1.



LEGEND: 1 – Most important faults of the structural set: Gorica – Ilirska Bistrica – Rijeka fault (1), Southern Alps fault (2), Fella – Sava – Karlovac fault (3), Periadriatic – Drava fault (4), Zagreb fault (5), Brežice – Koprivnica fault (6); 2 – Other important faults; 3 – Parts of the faults with the dominant horizontal component of the fault side movements; 4 – Regional structural units: Southern Alps (SA) and Prealps (AF), Eastern Alps (EA), Dinarides (D), Adriatic microplate (AMP), west part of the Pannonian basin (WPB – Savske bore – 1, Slovenske Gorice – 2), south part of the Pannonian basin (SPB); 5 – direction of the Adriatic microplate movement; 6 – directions of the parts of the structural units; 7 – Medvednica

Fig. 1. Regional geologic structural relations (Pribičević et al. 2007).

According to structural classifications, the bridge is located near the area of structural units of the Eastern Alps and the Western part of the Pannonian Basin. In this section Slovenske Gorice and Maribor – Ptuj sub-basin stand out. In a narrower sense the bridge is located in Slovenske gorice. It should be noted that the Pohorje and Kozjak belong to the Eastern Alps. Western contact zone in the area, covered in Fig. 2, presents the fault zone Šentilj – Maribor – Malečnik – Trčova. The same fault around Maribor stretches along the Slovenske Gorice and Maribor – Ptuj sub-basin.

On the surface of Slovenske Gorice mostly marl, sandstone, limestone and sandy marl of the middle miocene age dominate. Quaternary river coatings are applied in all major valleys (Q). Dacite and andesite tuffs (M) were discovered only in two places of outcrops, indicating volcanic activity in the Miocene. Gravels, sands and clays of the quaternary (Q) age are present on the planar part of Maribor – Ptuj sub-basin. On the Kozjak near Maribor the described rocks of the middle miocene (M2) are also present on the surface. Some typical rocks of the Eastern Alps can be found west of Kozjak: gneisses, amphibolites, phyllites and sandstones from the paleozoic.

On the surface of Slovenske gorice, marls, sandstones and limestones from the middle miocene are mostly oblique and horizontal and their different provision is also noticeable. This indicates the wrinkling of rocks, the existence of certain structures and their various shifts conditioned by tectonic movements.

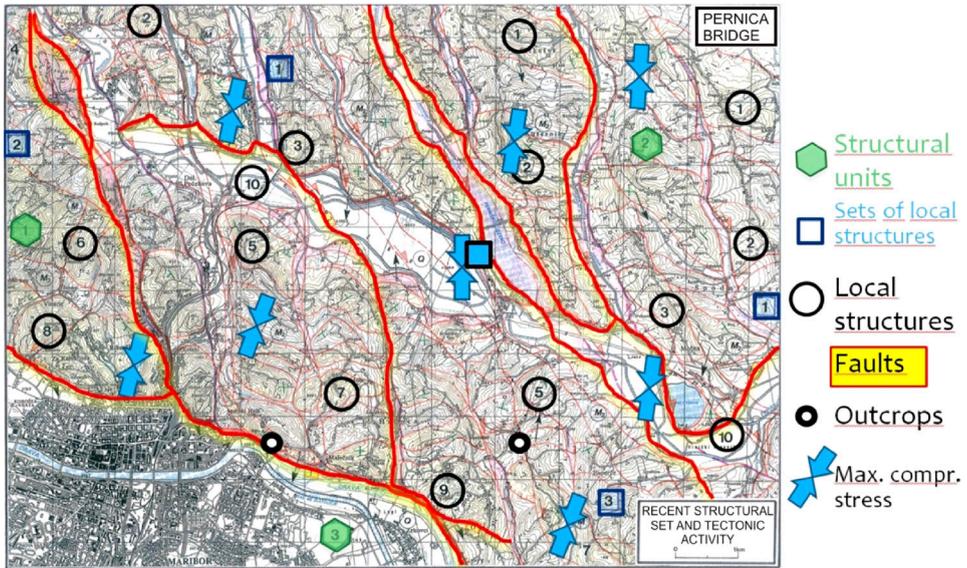


Fig. 2. Structures and faults in the relief for Pernica bridge.

The collected structural and geological data indicate that the structural set of the Slovenske Gorice (2) consists of a series of local reverse structures along which the reverse faults of the opposite vergence are spreading (Fig. 2). The existence of a reverse structures and faults are indicating dominant compression of this recent structural set. Structures are extensively intersected by faults in the NNW–SSE direction. One can identify the gaps and displacements of individual structures along the stretch. Some local structures stand out as the rising hills. A reverse faults of the opposite vergence are stretched between the raised portions of the relief along the steep slopes. In the relief, faults of the NNW – SSE direction (extending as deeply cut valleys mostly in straight-lines) are particularly noticeable. It should be noted that (due to the provision and position of the reverse structure) in Slovenske gorice (2) two relatively large series of a locally raised reverse structure stand out: Gradiška – Pernica lake – Partinje (1) and Košaki – Celestina – Vaniška vas (3). In both series there are three more prominent local reversing structures. Between the specified series in Pesnica valley, a relatively big suspended structure is recognizable. It is wedged between the reverse faults of the opposite vergence. Also the set Slemen – Pošpeh – Ribniško Selo (2) and two larger local reversing structures stand up in the part of Kozjak.

Numerous faults affect characteristics of the structural set. Two systems are notable: W – E (reverse faults which are parallel to the structural sets and parallel to the raised local reversing structures) and NNW – SSE (normal and reverse faults that intersect the local structures and sets of structures). The faults of a system NNE – SSW occur only locally. Faults are always presented as zones of different widths.

The most important in the discussed structural part is the Šentilj – Maribor – Malečnik – (1) fault. This is the zone with the width of 100–600 m between the

major faults. Its major branches are also important: Gradiška – Maribor fault (2) and Pesnica fault (3). Those branches also form the zones. Together they occupy a wide space between the border of the Eastern Alps (1) and the Slovenske gorice (2). Numerous faults can be seen parallel to the above mentioned faults. It should be noted that the Šentilj – Maribor – Malečnik – Trčova fault (1) and its branches in Maribor are abruptly changing direction. At the outcrops along the Drava river some faults from the main zone and zone branches were discovered (Fig. 3 and Fig. 4 – the measuring point T1). Shifts of the layers of marl or local faults suggest reversing displacements of the hanging side of fault to the S.

Raised series of local structures separate three faults: Pesnica – Pernica lake – Močna (4) fault, Maribor fault (5) and Malečnik – Metava fault (6). The faults are reverse with vergences or shifts of overlying wings to the S and SSW. Reverse faults stand out parallel to the individual locally raised structures. The most prominent parts of the structure and reverse faults of opposite vergence can be noticed. Some faults have wider zones, such as the fault along the edge of the Pesnica valley between Pesnica and Dolnja Počehova.

The structural set includes particularly important faults of the NW – SE direction. Those faults have the parallel provision. Major fault zones and branches of varying inclination and character (normal, reverse) can be seen. In the relief of their zones, cutted valleys often occur as flatline direction. The most important are Pernica fault (7) and Jakobski Dol fault (8). Their zones are between 300 m and 500 m wide.



Fig. 3. T1 – at road Maribor – Malečnik: Šentilj – Maribor – Malečnik – Trčova (1) fault.



Fig. 4. T1 – layers of marl: a) two parallel faults, b) fault in the zone.

The bridge is located in the outskirts of the local reverse structure of Pesnica – Pernica lake – Spodnje Partinje (3). Pernica fault zone (7) stretches through Pernica lake. Faults from the zone are normal around the lake. Right shifts of the local structures can be noticed. There are main branches of the aforementioned faults across the bridge. Right horizontal component of the wing movement are also prevalent along these faults. Between the bridge and Pernica village the fault Pesnica – Pernica lake – Močna (4) is shifted about 600 m to its right (Fig. 2).

Recent tectonic movements and especially present right horizontal components of the side of fault movement, in which zone this bridge is situated, most certainly affect the structure of the bridge. The position of the discussed areas in the regional structural set is important for the impact assessment. Key information is provided by the occurrence and concentration of earthquakes. In the vicinity of the bridge in the Eastern Alps and the Slovenske gorice, most frequent earthquakes are relatively weak – intensity magnitude up to 4.9. The earthquake of magnitude greater than 5.0 in Slovenske gorice was about 20 km ESE from location of the bridge. The most active part of the most important structural set closest to the observed location is taken into account to estimate the maximum possible earthquake magnitude around the bridge. In this case this is the fault Pesnica – Pernica lake – Močna (4). Based on the location of the structural set, the most active part of the fault stretches between villages Gradiška north of Maribor and Pernica fault zones (7) at the length of about 6 km. *According to international standards (Wells and Coppersmith 1994) in the area of fault of the most active part the earthquakes of magnitude between 5.7 and 5.8 are possible.* The same maximum earthquake magnitude is possible in the area of the most active part of the fault Šentilj – Maribor – Malečnik – Trčova (1) along the Drava river in the length of about 5.5 km.

To assess the bridge safety in micro scale a load test of the bridge was made. The results are presented in next chapter.

4. Bridge and load test description

As a real model for simply supported structure, the old bridge over the Pesnica River in Pernica near Maribor was chosen (Fig. 5). The bridge was built in 1968 and renovated in 1992. It is therefore a senior facility through which there is no longer traffic, as the result of the new highway Maribor – Murska Sobota in the vicinity. Unfortunately, a newer bridge was not found, because at that time the technology of bridge structure building made great breakthroughs and simply supported constructions are almost not constructed any more.

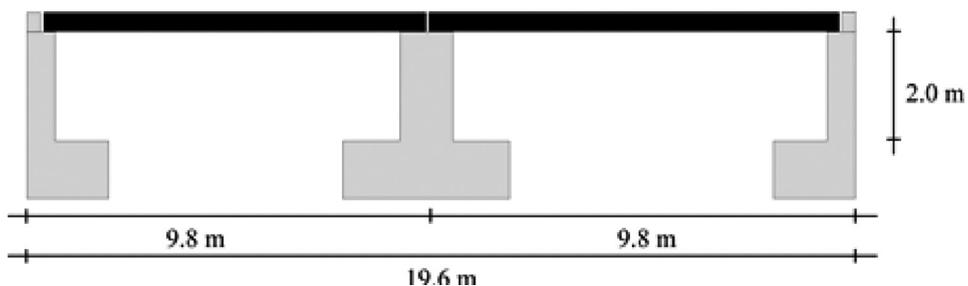


Fig. 5. Pernica bridge – the sketch.

The bridge is 19.6 m long, 7 m wide and 2 m high. It is reinforced concrete bridge with two simply supported spans (Fig. 6). The bridge is constructed of 10 concrete carriers of 0.7 m width, laid one to another (Fig. 7).



Fig. 6. *Pernica bridge across the Pesnica river.* Fig. 7. *Beam as a supporting structure.*

The measurements of the object response to a static load (2 examples), which was caused by the 14 725.00 kg truck (Mercedes Actros 4141), were conducted during load tests. Dynamic load test was performed with the same truck driving through the bridge at 20 km/h, 30 km/h and 50 km/h (Štrukelj and Kamnik 2010). For geodetic measurements two electronic total stations Nikon DTM 720 were used (Fig. 8 and Fig. 9). Both instruments stations have been prepared on the left bank of the Pesnica River. For the measurements retro tape targets were fixed to the middle of the second field.



Fig. 8. *Total station 1 on the Pernica Bridge.* Fig. 9. *Total station 2 on the Pernica Bridge.*

A temporary scaffold was erected for an inductive transducer under the bridge (Fig. 10). The inductive transducer measured the response to a static and dynamic load and, as such, represents a reference measurement which can be later

compared to other measurements. In order to monitor the dynamic response on the bottom of the bridge, accelerometer has been mounted as well. Furthermore, during the load test the strains were measured using one 10 cm long strain gauge glued near the inductive transducer and accelerometer (Fig. 11). The surface of the concrete was prepared according to the recommendations (Kamnik et al. 2015).



Fig. 10. Scaffold under the bridge.



Fig. 11. Sensors under the Pernica Bridge.

Fig. 12 shows filtered signals of inductive transducer, accelerometer and strain gauge measured at the dynamic load case (at 30 km/h). The green line shows the

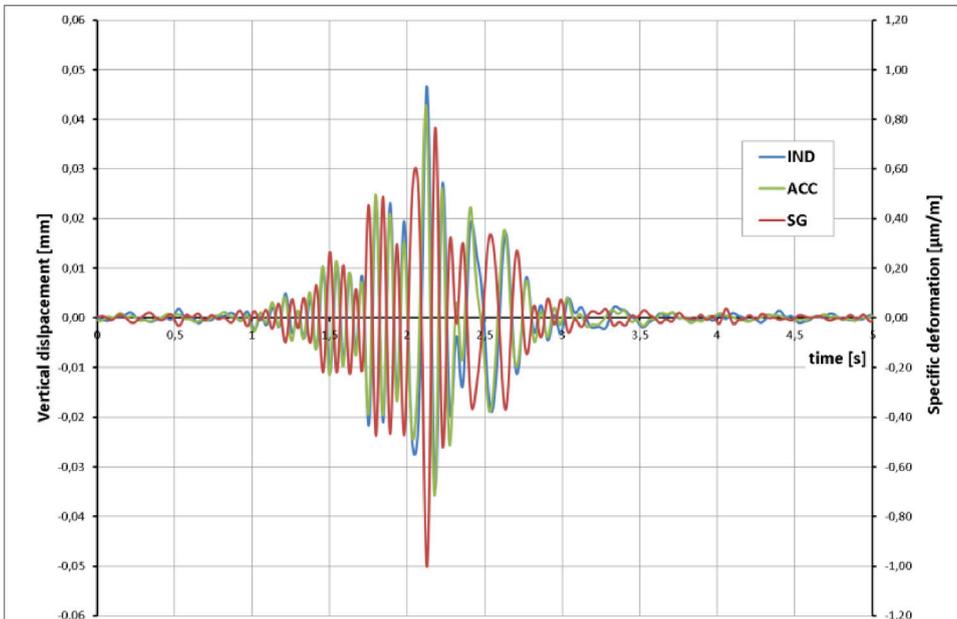


Fig. 12. Measured signals at dynamic part of the load test.

signal of accelerometer (already twice (by time) integrated using Bruel&Kjær Type 2635 charge amplifier). The red line shows the signal of strain gauge and the blue line is the signal of inductive transducer. The signals are practically identical one to each other which means, that the reference was solid and stable and all sensors were well calibrated.

Then two examples of a static load were performed. Fig. 13 and Fig. 14 show the position of the truck in a static load situation 1 and 2. The vehicle was positioned so that the last two tires of the truck were exactly over the sensors mounted below.



Fig. 13. *Static example 1 (on the left driving lane).*



Fig. 14. *Static example 2 (on the right driving lane).*

The measured specific deformations versus time for a static example 1 are shown in Fig. 15. In this case the average strain was $15.3 \mu\text{m}/\text{m}$. A very good agreement with the signal of inductive transducer (taken as a reference and measuring the vertical displacement) can be seen.

Fig. 16 shows specific deformations after they were multiplied by the average proportionality factor $\bar{\kappa}$ (-0.04975) calculated using the dynamic acceleration strain ratio (DASR) method (Kamnik 2014). A very good agreement with the signal of inductive transducer (taken as a reference) can be seen.

The results of static measurements are shown in Table 1. A proportional κ ratio in column 2 is multiplied by the measured strain at static load (column 3). The vertical displacement, measured by the inductive transducer (considered as a reference measurement), is shown in the column 4. The displacements were measured also with the total station (TS) in the local coordinate system. The

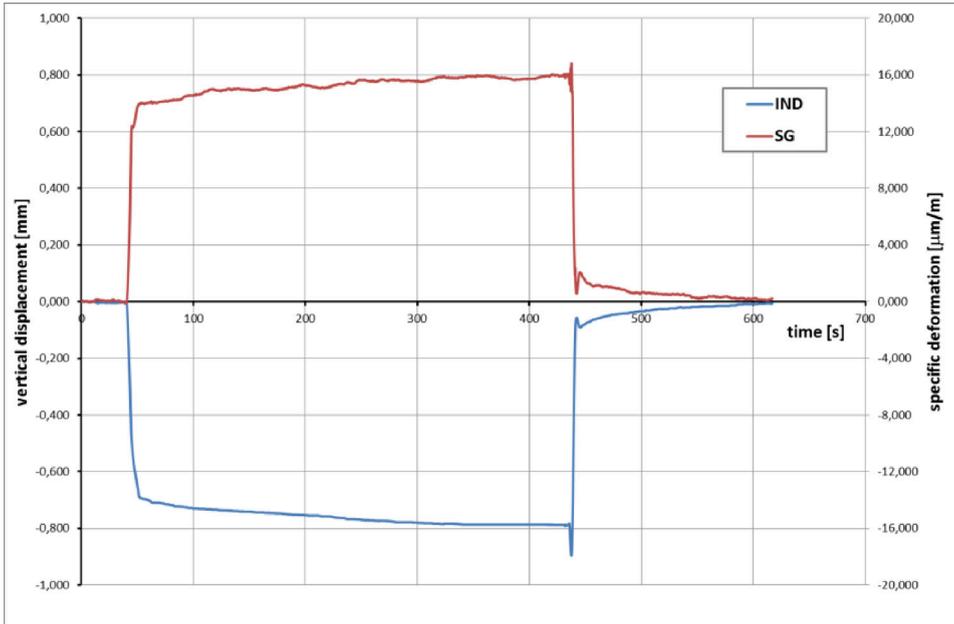


Fig. 15. Signal of strain gauge and inductive transducer at static example 1.

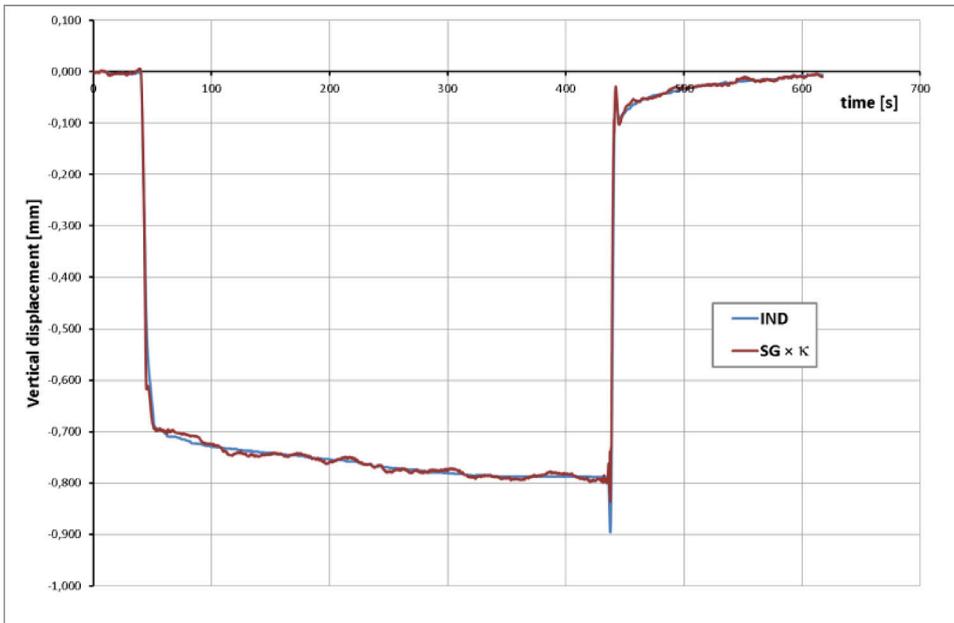


Fig. 16. Signal of inductive transducer and strain gauge multiplied by κ .

measurement can be seen in column 5. The calculated vertical displacement (using κ -ratio and DASR method) can be seen in column 6.

Table 1 shows the measured vertical displacement with the inductive transducer for a static examples 1 and 2. A proportional κ ratio in column B is multiplied by the measured strain at static load (column C). The measurements with the inductive transducers are in general very accurate because the sensor is in direct contact with the measured surface so inductive transducer measurement can be taken as a reference. This measurement is compared with the vertical displacement measurement made by total station (column D – TS). As it can be seen geodetic measurement are different for 0.06 mm (static example 1) and 1.2 mm (static example 2). The vertical displacement obtained by the DASR method (column F) is closer to the reference values than obtained by the direct geodetic observations (column E).

Table 1. Comparison of vertical displacements.

Static example	Proportional factor $\bar{\kappa} \left[\frac{\text{mm} \cdot \text{m}}{\mu\text{m}} \right]$	Measured spec. def. [$\mu\text{m} / \text{m}$]	Vertical displacement [mm]		
	ACC / strain gauge	Strain gauge	Measured ind. trans.	Measured TS	DASR 2 · 3
A	B	C	D	E	F
1	-0.04975	15.300	-0.76	-0.7	-0.76
2		14.628	-0.72	-0.6	-0.73

Because the bridge span is pretty short against the applied load the according vertical displacement is also pretty small. Geodetically measured vertical displacement is therefore very close to the accuracy of geodetic measurement, estimated on 0.3 mm. To obtain better geodetic results more load should be applied on the bridge. In the case of a very small vertical displacements a DASR method is recommended.

5. Conclusion

The amplitudes of the recent movement developments of any point on the surface can be determined by geodetic measurements. Older and also recent tectonic shifts are determined by field geological measurements in zones of tectonic faults. Where possible, it is required to compare the data obtained from geological and geodetic measurements. It is important to point out that the Earth's crust, including surface area, has geological structure built from the rocks of different composition and density. Some structures and their relationships, positions in space and shifts represent a structural set of an area, which is included in regional units, and smaller or larger portions of the earth's crust known as the Earth's plates and micro plates. The most important fact is that the tectonic movements are always

present around locations of considered bridges. Therefore, it is certainly necessary to define in detail their characteristics due to the potential impact on those individual bridges.

It is necessary to make a plan for each load test. After visual inspection, we can begin to test the structure under external (useful) load, which depends on the function of the building. This takes into account the fact that the facility is under such load which, by their intensity and schedule, represents the maximum impact on it. The results obtained with the load tests show, in addition to everything else, the level of security of the building. When applying the load to a bridge (during the loading test) the structure should never be loaded over the serviceability limit state, so the bridge remains in an elastic state. But again the load on the bridge should be such that some situations on/in the bridge do actually occur and can be correctly measured.

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Recentni strukturni sklop i probno ispitivanje jednostavno poduprtog mosta Pernica

SAŽETAK. Objekti i njihovi međusobni odnosi, mjesta u prostoru i promjene predstavljaju strukturni sklop područja, koji je uključen u područnim jedinicama i u manje ili veće dijelove Zemljine kore poznate kao Zemljine ploče i mikro-ploče. Najvažnija je činjenica da su tektonski pokreti uvijek prisutni oko mjesta promatranja mosta. Dakle, svakako je potrebno preciznije definirati karakteristike strukturnog sklopa zbog mogućeg utjecaja na pojedine dijelove mosta. Recentni strukturni sklop tako je bio napravljen za jednostavno poduprt most Pernica. Da bi se ocijenila sigurnost prilikom upotrebe, napravljeno je i probno ispitivanje mosta.

Ključne riječi: probno ispitivanje, recentni strukturni sklop, mjerenje naprezanja, induktivno osjetilo, akcelerometar, izmjera mosta, metoda DASR.

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