Importance of geologic study and load test of log pod mangartom arch 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 Log pod Mangartom. To assess the bridge in micro sense the load test of the bridge was performed.

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 the bridge. Studies for the location of a bridge are made on small scale maps (Kapović, 2010) 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. 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 position of the Log pod Mangartom in relation to the assessments of recent tectonic movements that can be expected at the viaduct 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, 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 load tests 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’s 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 and Nanni, 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, Dodson and Roberts, 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 (Dicleri and Bruneau, 1995, Law, Chan and Zeng, 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, Chan and Yu, 2007, Obrien 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, Zhang and Gao, 2005. To assess the Log pod Mangartom 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 Beljak and Ponteba (Jurkovšek, 1985) 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, Castellari and Canelli, 2000, Vrabec and Fodor, 2004). Especially prominent works of seismo-tectonic relationships, stress regime and geodetic-geological data on recent tectonic movements (Ribaric, 1983, Del Ben et al., 1991, Grünthal and Stormeyer, 1992, Wells and Coppersmit, 1994, Miskovic et al., 1998, Altiner, 1999, Poljak et al., 2000, Pribicевич, 2001, Pribicевич et al., 2002, 2003, 2007, Grencerczy and Kenyeres, 2004, Bada et al., 2004, Đapo 2009) are considered.

3. Recent geologic structural set and the tectonic activities for log pod mangartom bridge

In order to collect necessary data about the location of the bridge, 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 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 which forms the structural set.

The first notable regional structural set (Figure 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 – Sava – Karlovac (3), Periadriatik - 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 viaduct. However, the magnitude of the most earthquakes is up to 4.9. In this region, three epicentral areas with earthquakes of a great strength can be noticed (Ribaric 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.
Figure 1. Regional geologic structural relations (Pribičević et. al., 2007)

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 Panonian basin (WPB – Savske bore -1, Slovenske Gorice – 2), south part of the Panonian basin (SPB); 5 – direction of the Adriatic microplate movement; 6 – directions of the parts of the structural units; 7 – Medvednica

The bridge is located in the northern part of the Julian Alps. The space compression of the Julian Alps induced with the shifts of the Adriatic microplate, so the largest tectonic activity and shifts are particularly pronounced along the reverse faults with vergence towards N. The most important faults of the mentioned vergence are next to the sets of locally raised reverse structures. Individual structures are built mainly of limestone and dolomite of Triassic age on the surface. Outcrops of Jurassic limestones and limestones and marly limestones of Cretaceous age at Mangart (6) and the Loška stena were discovered only occasionally. Quaternary moraines, dunes and river deposits in large valleys and on the slopes of some rivers were found.

Figure 2. Structures and faults in the relief for Log pod Mangartom bridge
In the discussed structural part reverse structures are present. The expressed compression space conditions the formation of reverse structure sets and reverse faults of the opposite vergence are present along walls. The fault zones are very often. Rapid narrowing of the set space conditions the cracking and faulting of the carbonate rocks and formation of the alpine terrain. Structures and faults reflect in the relief very clearly. This is the sign that the tectonic movements are constantly present. The most raised parts of the relief indicate the positions of the local reverse structures. River valleys parallel to the structures represent locally suspended structures. Four local reversing structures sets are present (Fig. 5) Vetta Scabra (4), Ruša - Mangart (6), Planja - Mežave (7), Vogel – Kolovrat (8) and three suspended structures Jezerska valley (11), Predel – Mangart stream (12) and Koritnica (13) are present around the bridge site. The relief has very noticeable faults. In the zones, deep, broad and often straight-line valleys, steep slopes and cliffs (Fig. 3, 4, 5) are formed. Cut valleys are very frequent in the most prominent parts of the local reverse structures in the zones of local faults of various origins. The position of the local reverse structure allows us to point out a three structure series: Monte Florianca - Monte Re - Valromana - Planica, Predil - Grintavec - Mangart - Ponca (2) and Kanin - Loška Stena - Jalovec (3). Within these series there are nine local reverse structure and four large suspended structures (Fig. 2). The most important faults of the discussed structural set extend along the borders of locally raised reverse structure. They are always presented as zones. The faults are reverse, vergency towards N. The fault Sella Nevea - Strmec - Koritnica (2) is nearest to the Predel bridge and next to the structure series Kanin - Loška Stena - Jalovec (3). The measurement point T1 presents the zone of parallel faults in the outcrop. Clear stretches are visible on the surface. Their position is 205°/80°/60°/reverse left (Fig. 4). In the Koritnica valley, the same fault has the position of 155°/70°/70°/reverse left (Figure 2).

![Figure 3](image-url) Fault along locally risen reverse structure Planja – Mežave (7); Mangart (6)

![Figure 4](image-url) a) Point T1 – Predel; b) Stretches in the surface of the fault with the position 205°/80°/60°/reverse left

The most important structural faults assembly includes four faults of NNE - SSW system. They are presented as the zones of parallel faults. Diagonally reverse left shifts at the relatively small angle were measured on some outcrops. The most noticeable is the Tarvisio - Lago di Predil (3) fault. In its wide zone, a deep valley was created. The main faults from the zones extend along the east side of the valley; the zone width is 100-150 m. The main outcrop restricts the valley to the west. The valley width is 200 - 500 m. Around the Predil lake some smaller branches with normal walls shifts were observed. Three outcrops were selected. At the T2 measurement point (east of Cave del Predil), cliffs in relief in the hanging wall of the main fault 3a is located. Measured position was 105°/75°/20°/reverse
left. One larger outcrop of the same fault 3a of the observed zone was detected. There are noticeable parallel faults in the zone. Measured position was 100°/70°/20°/reverse left. Outcrops of the main branch of the observed fault are best discovered in Cave del Predil. Parallel faults in the zone with widths up to 50 m and position 305°/75°/45°/reverse left can be noticed at the entrance to the mine in the Dolomites. Southwest to the Predil lake the main faults of the observed zone are covered with the zone of the fault Sella Nevea - Strmec - Koritnica (2). The route of the main branch in this part of Jezersko valley probably ends.

Figure 5. Structures and faults around the Log pod Mangartom bridge

The recent tectonic activity indicates occurrence of earthquakes. In the Julian Alps there are concentrations of earthquake epicenters especially in their peripheral regions. The strongest earthquake of magnitude 5.9 occurred about 13 km southward from the bridge location. For the determination of the maximum earthquake magnitude that can occur around the observed locations, the length of the possibly most active parts of the most important structural set faults are taken into account. These are the following faults: Mrzla voda – Cave del Predil - Lagi di Fusine (1) and Sella Nevea - Strmec - Koritnica (2). The parts of the fault with cross reverse shifts of the hanging wall are very important. In these areas there are always the greatest compression and concentration of the earthquakes. From the fault Mrzla voda - Cave del Predil - Lagi di Fusine (1), the part between the valleys Valromana and Lagi di Fusine of the length of 5 km is taken into account. From the fault Sella Nevea - Strmec - Koritnica (2), the part south of the bridge location to the valley Koritnica in the length of about 4.5 km is the most active. In this area the possibility the an earthquake of magnitude 5.6 to 5.7 is quite high according to the international standards (Wells & Coppersmith, 1994). However, the fault Fella - Sava which extends to the northern edge of the Julian Alps is also very important for the bridge location. The part between Tarvisio and Podkoren at the length of about 12 km is considerable. There is a concentration of the earthquakes in this area. The occurrence of earthquakes with a magnitude of about 6.3 is possible. It can be concluded that the Log pod Mangartom Bridge is affected by reverse tectonic movements that cause narrowing of the space around the bridge and especially the left horizontal displacements in the zone fault Valromana - Log (4). Around the site of the bridge, earthquakes of magnitude 5.6 to 5.7 can be expected. In the area of the zone fault Fella – Sava, earthquakes with a magnitude of about 6.3 can occur. The route of this fault is 7.5 km away from the location of the bridge. The tectonic activity has long term influences on the built structures, but the bridges, viaducts and other buildings are made for daily exploitation. Therefore, the behavior of the structure on a daily basis should also be investigated. So a load test can ensure a lot of information on this issue. Load tests should always be performed for a little bit complex structures. The bridges are also under pressure (exploitation load, wind, snow, rain,...) on
a daily basis.

4. Log pod mangartom bridge and load test description
The bridge is 128.01 m long and more than 60 m high with five supports; the arch is 87.16 m long, see Fig. 6. The bridge is situated on the road close to the Italian-Slovenian border crossing Predelj in the north-west part of Slovenia. The bridge was built up in 2009. It is a specific object in the Slovenian area because of its placement in space, bypassing more than 60 m deep canyon. Its concrete structure has three supports on each side. An arch is 94 m, the bridge’s total length is nearly 130 m (Figure 6).

The load test was carried out with one lorry of 27,586 kg. First, the dynamic part of the load test was performed (Figure 7). The truck drove over the bridge three times at different speeds (20 km/h, 40 km/h and 50 km/h). Then the static part of the load test was performed (Figure 8) – the lorry was standing in the center of the arc and stood there until geodetic survey was completed. Only one static example was made.

5. Data of the measurement equipment and methodology
The approach to the bridge with geodetic equipment was rather good, so the measurements with the method of trigonometric heights using the Nikon DTM 720 total station was performed. Slope distance from the instrument station point to the point in the middle of the bridge was 81.3 m. Three points were observed on the bridge (on the left and the right ends and in the middle of the span). The points were signalized using Leica retro tape targets of 4.5 cm x 4.5 cm. Two points were signalized outside the bridge for the orientation and control. Two sets in face one and two of the instrument were measured.
Four strain gauges were applied on the reinforcement bars before casting the concrete. During the load test only two strain gauges were still useful. The middle of the span was instrumented with two accelerometers (Figure 9) for measuring the dynamic response of the bridge.

![Image](image1.png)

**Figure 9.** Measurement equipment on the bridge

The measured signals of strain gauges can be seen in Figure 10. Because the scaffolding under the bridge could not be built, the inductive transducers could not be used. The only independent static measurement in this case was geodetic measurement using total station.

![Image](image2.png)

**Figure 10.** Signal of strain gauges at static load

Figure 11 shows the vertical displacements determined by the dynamic acceleration strain ratio method (using strain gauge SG-2 measurement multiplied with dynamic acceleration strain ratio obtained between accelerometer ACC1 and strain gauge SG-2 and strain gauge SG-3 multiplied with dynamic acceleration strain ratio obtained between accelerometer ACC2 and strain gauge SG-3) together with the vertical displacements obtained from the geodetic measurement (4.3 mm with total station) (Kamnik, 2014).
Figure 11. Calculated vertical displacements at static load

With the total station by the method of trigonometric heights measurements on five points were performed (one in the middle of the arc, two on the both abutments and two control points outside the bridge). The points on the bridge were Leica reflective tape target dimensions of 4.5 cm x 4.5 cm. Outside the bridge two prisms were stabilized serving for orientation and control. Points were measured in two sets in both faces of the instrument. The standard deviation of the determination of vertical displacement was 0.36 mm.

The vertical displacement on the middle of the span was measured with the total station (4.3 mm). A computer simulation of static load test on the 3D model of the object was also performed. Taking into account the actual material and geometrical characteristics of the object and actual load, the computed value of the vertical displacement in the middle point was 4.2 mm. A 3D model and graphical representation of the results of the calculation are shown in Figure 130. The comparative static calculation was carried out by the finite element method (FEM) with 64913 tetrahedral elements with characteristic spatial dimension of 0.5 m.

6. 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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