Geotechnical Reconnaissance and Engineering Effects of the December 29, 2020, M6.4 Petrinja, Croatia Earthquake, and Associated Seismic Sequence

Chapter 9: Infrastructure Damage

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9. Infrastructure Damage

Infrastructure damage in Sisak-Moslavina County due to earthquakes on December 28 and 29 2020 that was recorded by the reconnaissance team, media and Croatian Roads is shown in this chapter. According to the Croatian Roads report, significant damages occurred on roads and bridges in Sisak-Moslavina, Karlovac, and Zagreb Counties. **Figure 9.1** shows an overview of the damage locations and causes as reported by Croatian Roads (Hrvatske ceste 2021). Reported co-seismic effects include cracks on roads and subgrade, re-activation of existing landslides as well as bridge columns, abutments, and bearings damage. The GEER reconnaissance was performed on bridges Brest, Galdovo, and Gromovi and Old Bridge in Sisak, while the rest of this chapter documents road damage as reported by Croatian Roads and media.

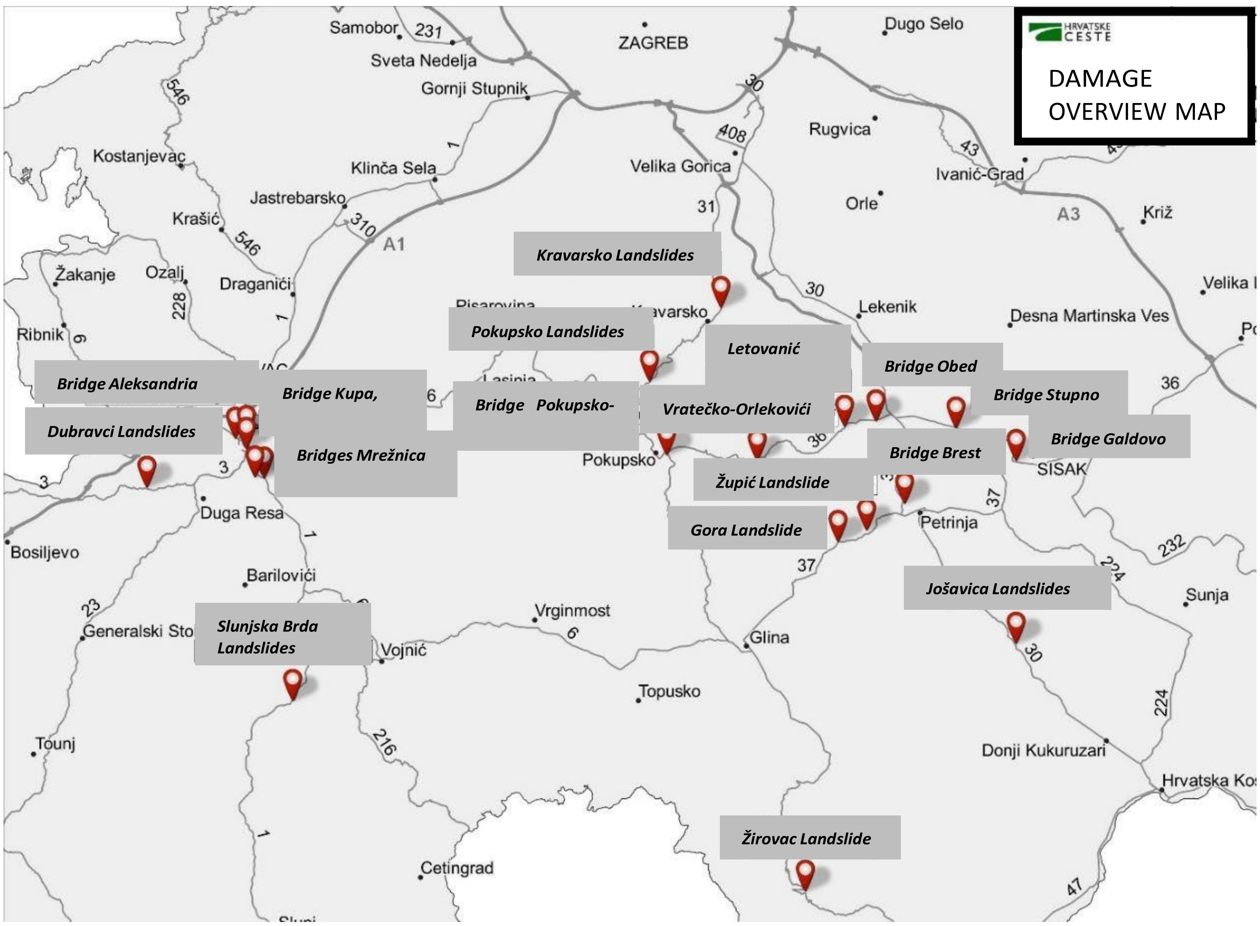

Figure 9.1 A comprehensive infrastructure damage overview map in Sisak-Moslavina, Zagreb, and Karlovac Counties (source: Hrvatske Ceste - Croatian Roads).

9.1 Damage to Roads

The Sisak-Moslavina County roads include 11 state roads with a total of 413 km length, 84 county roads, and 170 local roads in the length of 1226.56 km total, where 647.09 km are county roads and 579.56 km are local roads, 1009.05 km are asphalt roads and 217.60 km is macadam. On top of that, there is 2000 km of uncategorized roads (Sisačko-moslavačka županija, n.d.; Županijska uprava za ceste Sisačko-moslavačke županije, n.d.). **Figure 9.2** shows specific locations of reported road damage.

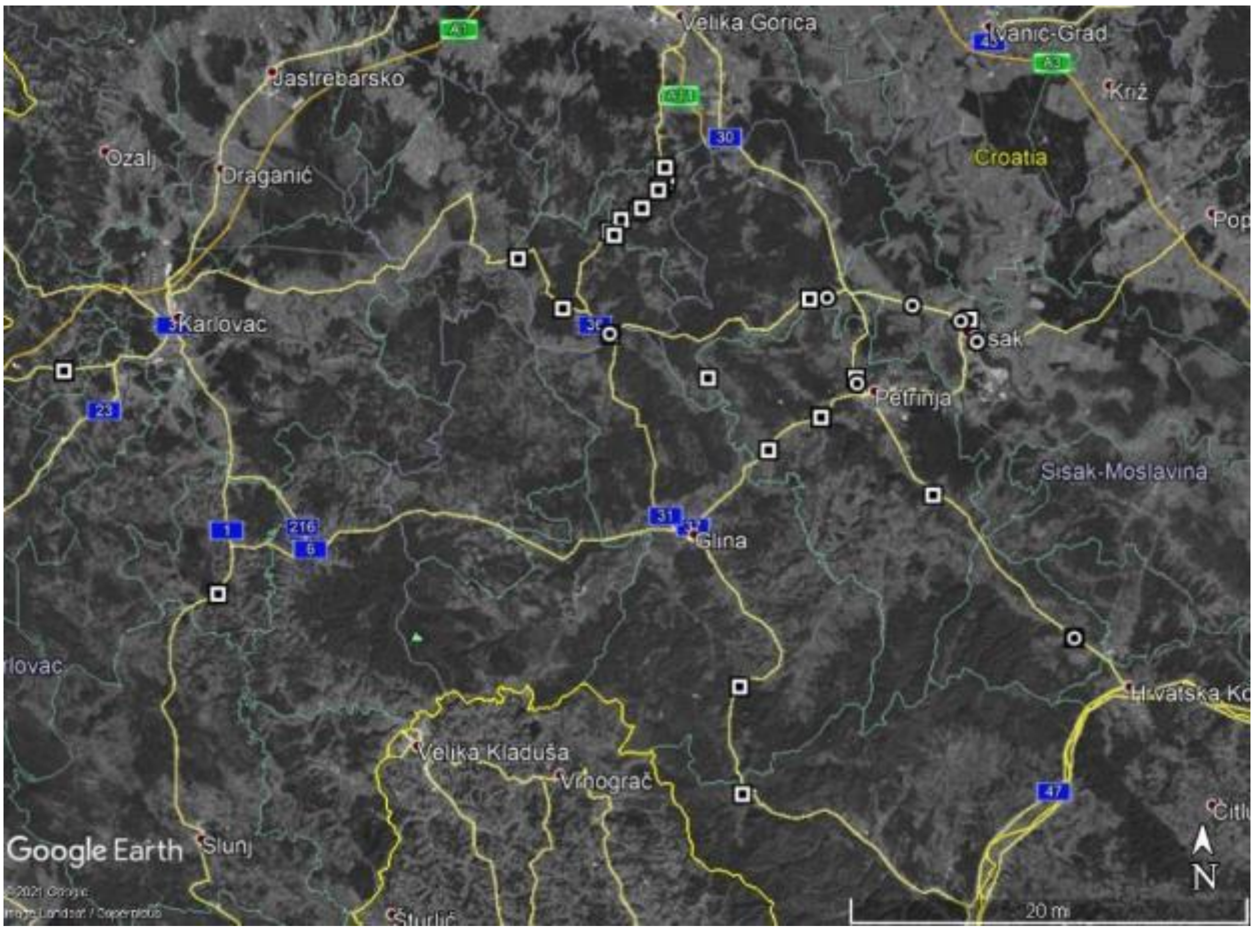

Figure 9.2 Specific locations of road damage (squares) and damaged bridges (circle) (Justin Wong and Ingrid Tomac).

Asphalt and subgrade cracking occurred on roads from which roughly 95% are in Sisak-Moslavina County. Asphalt damage in perpendicular, parallel, or inclined direction from the road axes occurred as opening cracks and, in several instances, accompanied with vertical displacements, as shown in **Figure 9.3**.

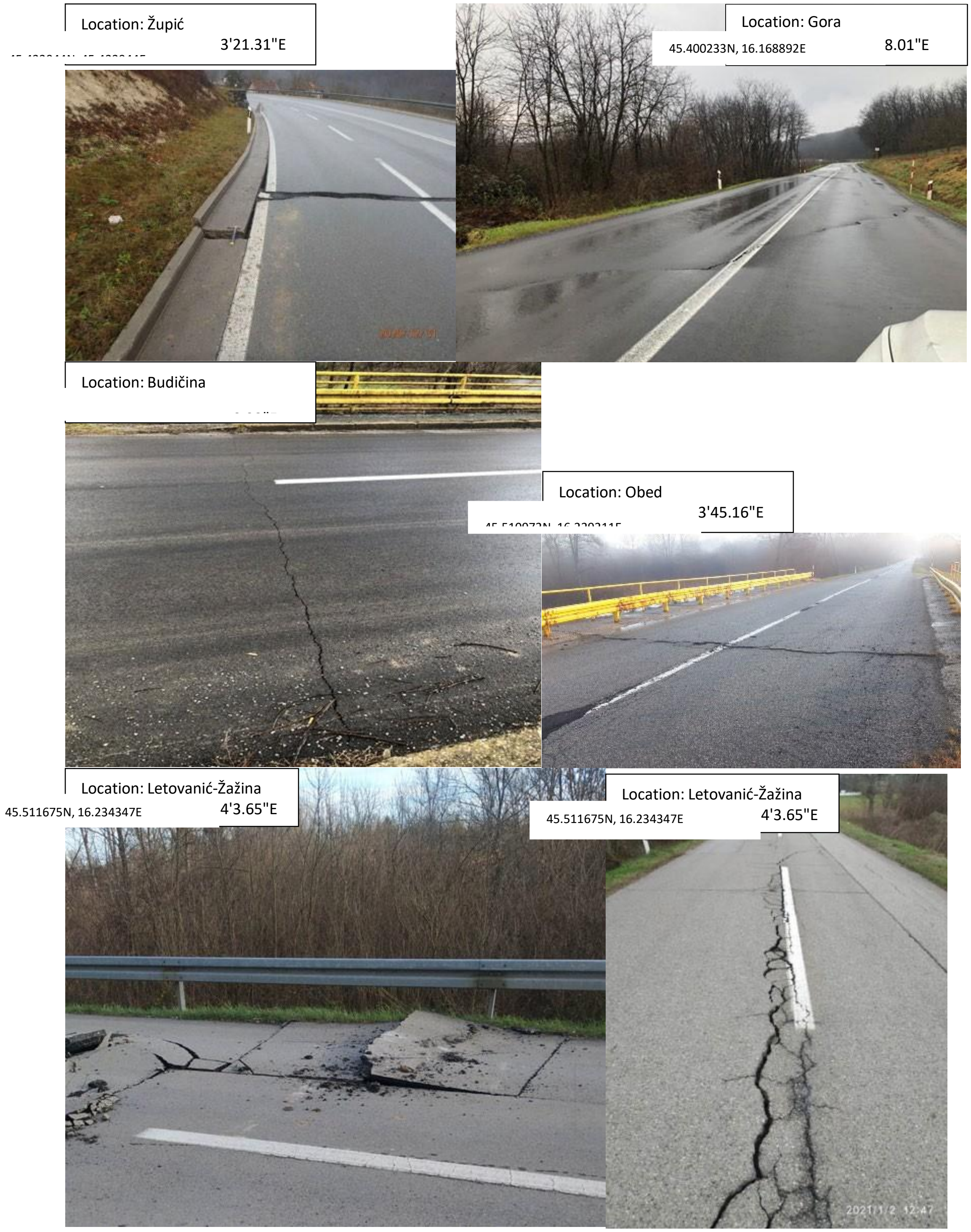

Figure 9.3 Horizontal and vertical displacement cracks in asphalt perpendicular, parallel, or inclined towards the road axis in several locations (Source: Croatian Roads – Hrvatske ceste).

Road damage was associated with an adjacent slope stability failure, either as a road embankment loss of stability or as re-activation of previously known landslides. Croatian Roads report a series of reactivated landslides with referral to previous road repair works, pointing that the slopes deformed additionally during the earthquake causing different levels of severity of road damage. Demonstrated effects span from thin asphalt cracks to cm-scale displacements, subgrade failure, and displacement and terrain slope displacement. Reported landslides are Landslide Županić, Landslide Gora, Landslide Jošavica, Landslide Vratečko-Orleković, Landslide Vratnik, Landslide Klasnić, Landslide Žirovac, 10 landslides on the state road DC31, landslide on the state road DC36, the state road DC1 near Brebornica, and the state road DC3 near Dubravci. **Figure 9.4** shows selected examples of a few severe sliding-related road damage as reported by Croatian Roads (2021).

Figure 9.4 Road damage accompanied with adjacent slope instability.

9.2. Damage to Bridges

Galdovo Bridge

Galdovo Bridge is a bridge across the Sava river in the Sisak suburb of Galdovo. The current bridge was erected at the end of the 1980s, but it incorporates 3 columns from a previous bridge at the same location (Novak, 1984; Radić, Žderić & Puž, 2007). The previous, through steel truss bridge is estimated to date from 1895 (Novak, 1984). The bridge superstructure is a 4-span continuous half-through steel girder structure. Cross girders support a concrete roadway slab. Pedestrian and bicycle paths are provided on both sides (Radić, Žderić & Puž, 2007). The three columns are made of brick, with partial stone cladding. There is no information available on the foundation design (Novak, 1984). The inspection in the 1980s, before the decision of erecting the new bridge on the existing supports, revealed that columns are in good condition, with no noticeable damage, cracks, or deformations, except at the top, immediately below the bearings (Novak, 1984). New cap beams were erected on top of columns to support the new structure (Radić, Žderić & Puž, 2007; Urbane ideje, 2018), as well as new bridge abutments, at a different location than those of the previous bridge (Novak, 1984; Radić, Žderić & Puž, 2007; Urbane ideje, 2018). The bridge was hit by a missile during the war in the 1990s, causing a rupture in the web of the main girder. The damage was subsequently repaired (Radić, Žderić & Puž, 2007). The bridge was once again repaired in 2019/2020 (dpreradus, 2020; Marković, 2020). The repair works addressed RC slab and steel bridge structure, as well as asphalt layers on the bridge and on the approach roads (Sisačko-moslavačka županija, 2019; Urbane ideje, 2018).

Figure 9.5 shows an aerial image of the Galdovo Bridge. Some liquefaction evidence in the proximity of the Galdovo bridge is shown in Chapter 7. Geotechnical soil reconnaissance revealed cracks in soil around the east abutment and the adjacent column on the left riverbank, while no visible soil surface damage was observed on the right riverbank near the bridge (**Figures 9.6** and **9.7**). It should be noted that there is a shaft in the area between the east abutment and the adjacent column to which some cracks in soil seem to be directed.

Figure 9.5 Galdovo Bridge over the river Sava (source: Google Maps).

Figure 9.6 Left Sava riverbank, east bridge abutment a) north face, upstream, b) north face, upstream and c) south face, downstream (45.4790N, 16.3854E).

Figure 9.7 Left bank of Sava, soil cracks between the abutment and the adjacent column (45.4790N, 16.3854E).

Damage suggests that the roadway slab rotated clockwise, where the western bridge portion displaced towards the north and the east towards the south. This can particularly be observed at the east abutment. Following are conclusions from the inspection carried out on February 6, 2021:

- There was a longitudinal displacement during the earthquake of at least 8 cm (**Figures 9.6** – **9.10**) – evidenced by pulling out of the railing at its expansion joint, and misalignment of the bridge finger expansion joint,
- There was a failure of transversally unmovable bridge bearing on the east abutment, and permanent 15-cm transverse displacement of the bridge (**Figures 9.6** and **9.9**). The bearings on the columns also suffered damage due to the bridge rotation.

In addition, concrete spalling was noticed on several joints of longitudinal steel girder-steel cross girder and concrete roadway slab.

Figure 9.8 Galdovo Bridge, displacement of the bridge expansion joint on the east abutment (45.4790N, 16.3854E).

Figure 9.9 Galdovo Bridge, 15-cm transverse displacement of the bridge railing (45.4790N, 16.3854E).

Figure 9.10. Galdovo Bridge, measuring longitudinal displacement on railing and expansion joint (45.4790N, 16.3854E).

Figure 9.11 Galdovo Bridge, damaged bearing on the east abutment (45.4790N, 16.3854E).

Figure 9.12 shows inclined trees on the riverbank, which typically indicate recent in inclined trees or historical in partially inclined trees slope instability. An absence of images and information before an earthquake makes it difficult to draw any conclusions about earthquake effects.

Figure 9.12 Inclined trees on the left bank of Sava river, the eastern side of the bridge, view towards the south (45.479N,16.385E).

As a part of the reconnaissance effort, a Lidar scan of what was identified as the bridge span with the most obvious damage was carried out on March 27, 2021, i.e., the bridge span between the east abutment and the adjacent column. 25 setups (**Figure 9.13**) were linked with 28 links in a bundle with a bundle error of 5 mm (NHERI RAPID Facility, 2021). The point cloud data obtained has not yet been fully analyzed, but it might provide further data. An example of the point cloud obtained is shown in **Figure 9.14**.

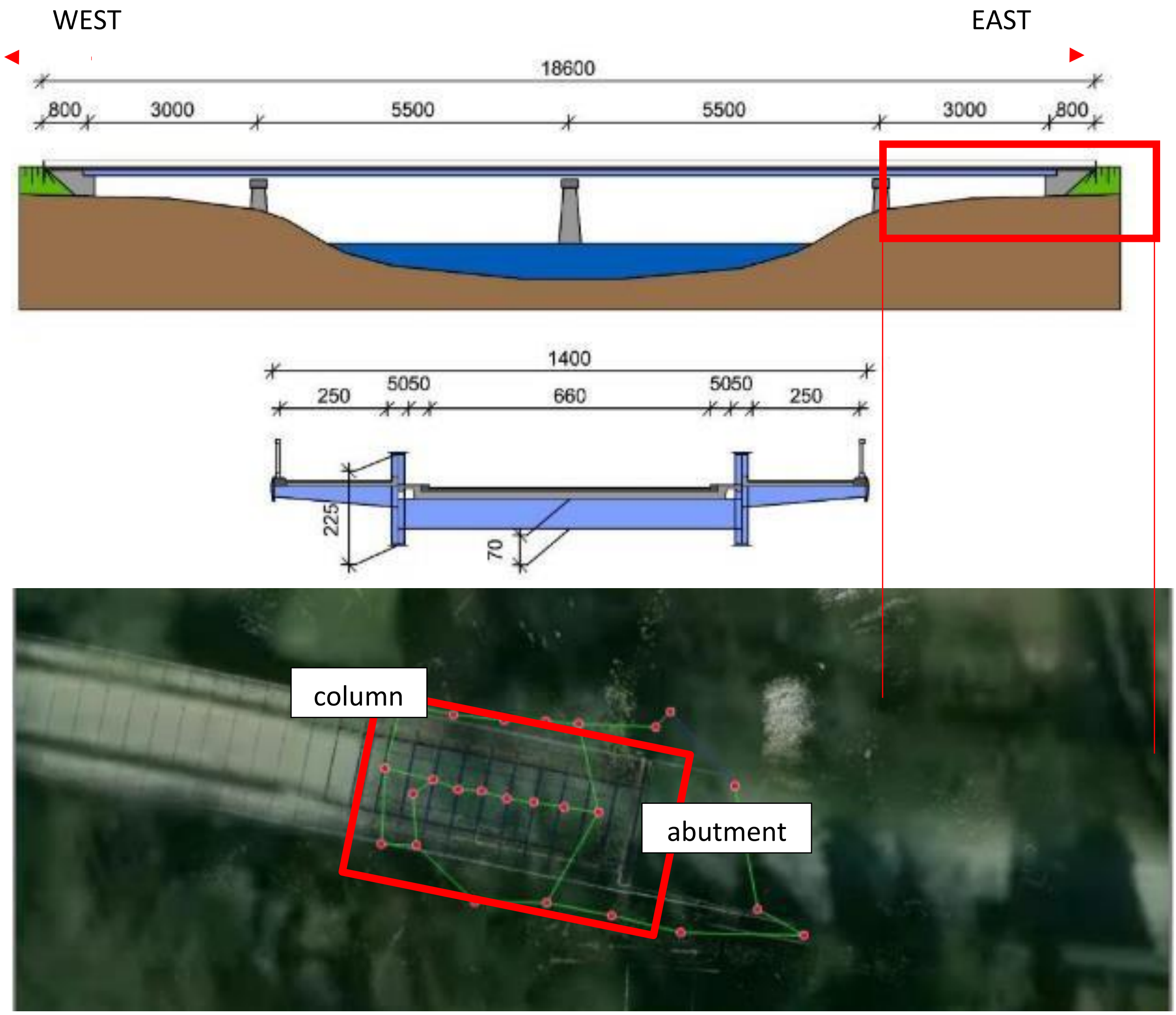

Figure 9.13 Galdovo Bridge, Lidar setups (location indicated on longitudinal bridge section obtained from Radić, Žderić & Puž, 2007).

Figure 9.14 Galdovo Bridge, Point cloud of the east abutment.

Gromovi Bridge

The original blueprint of the Gromovi Bridge dates from 1971, as shown in **Figure 9.15**. Gromovi Bridge is in Sisak and crosses river Kupa, with an axis oriented north-south. The bridge consists of a central 3-span structure, and approach viaducts at both sides. Bridge superstructures – in steel for the central portion of the bridge, and prestressed concrete for the approach viaducts, are supported by a series of 2-column piers consisting of 2 inclined columns and a cap beam with cantilevers on top. The piers of the approach viaducts are founded on shallow concrete spread footings, 4.5 x 4.5 m, 1.0 m deep embedded 2.5 m under the soil surface. Retrofit in 2019 focused on the steel structure of pedestrian passageways, the central bridge end columns, which provide a transition from concrete to steel superstructure and vice versa, and bearings on positions S13 and S16. The column S13 top portion, which had a crack, was strengthened with concrete anchors. Columns of the central steel bridge are founded on 100 cm in diameter reinforced concrete circular piles 10 m deep. There are 12 piles under each column. **Figure 9.15** shows the original bridge with the original foundation types.

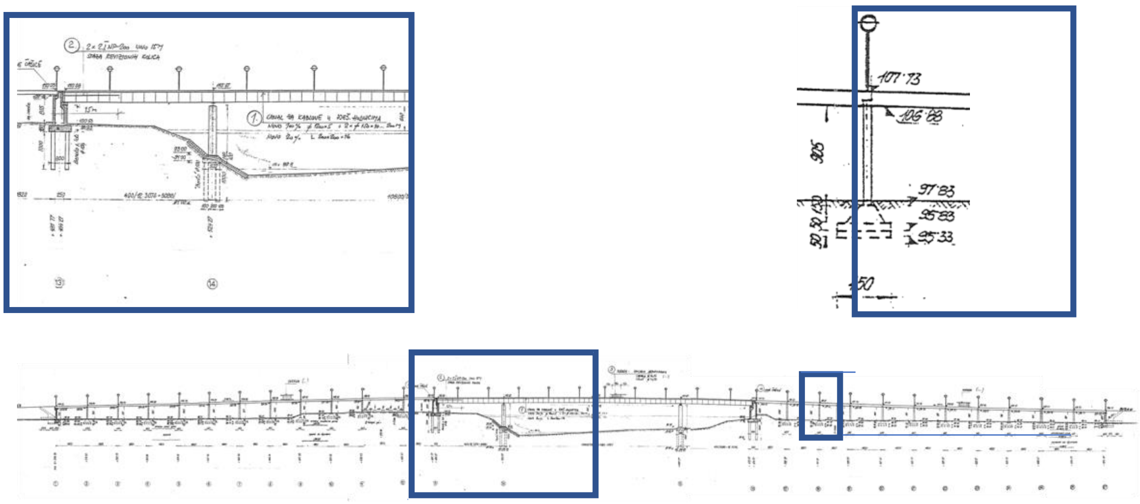

Figure 9.15 An original blueprint of Gromovi Bridge from 1970 (ŽPB, 2002).

Damage was detected after the earthquake on columns S4, S7, and S20 at the column-cap beam joint. On S4 (**Figure 9.16a**), the west column has horizontal cracks on the side facing south. On S7 (**Figure 9.156b**) the east column also has horizontal cracks on the south-facing side. On S20 (**Figure 9.16c**), the east column, the eastern and southern face at the top of the column show surface cracks.

Figure 9.16. a) damage at S4, b) damage at S7 and c) damage at S20. (source: Earthquake Petrinja 29 12 2021 GP HC_Road and bridge damage report", in Croatian).

Column at S13 is the edge column under the steel span on the northern side (**Figure 9.17**). Previously existing crack was repaired with concrete anchors during the retrofit in 2019. **Figure 9.17 b**) shows the side ramp as it was before the retrofit. The ramp is a reinforced concrete viaduct supported on elastomeric bearings, that suffered a visible crack on the asphalt along with the connection to the bridge and was sideways hitting the S13 column during the earthquake and caused local column damage, which is only superficial. **Figure 9.18** shows cracks on the soil surface between S4 and S5, which are in the east-west direction, perpendicular to the bridge longitudinal axis. To summarize, the damage on the Gromovi Bridge was detected on the columns and connections between columns and the roadway slab on the northern side of the Kupa river. The damage suggests a lateral spread of the northern embankment. It is interesting to note that most of the damage occurred on the parts of the bridge with shallow foundations, while the deep-founded bridge supports were not damaged. **Figure 9.19** links an aerial image obtained after the earthquake where liquefaction was detected on a wider area of the city of Sisak, including both sides of the Gromovi Bridge. The approximate position of identified damage is also shown.

Figure 9.17 a) reinforced pre-existing crack and dilation above on the column S13 on the northern side of the Kupa river and b) side ramp. (Source: Metal Projekt Ltd).

Figure 9.18 Cracks in soil between S4 and S5 (source: Hrvatske ceste 2021).

Figure 9.19 Aerial view of the area with "Most Gromova" bridge after the earthquake.

Brest Bridge

Brest Bridge crosses Kupa river at Brest, near Petrinja. The current bridge was erected in 1998 (DDmontaza, 2016), as the superstructure of its predecessor was blown up in 1991, during the war (Radić et al., 2007). The bridge superstructure is a 2-span continuous half-through steel girder structure. Cross girders support a reinforced concrete roadway slab. Pedestrian and bicycle paths are provided on both sides (Radić et al., 2007). The superstructure was erected on supports of the previous bridge, which were strengthened by adding new reinforced concrete cap beams (Radić et al., 2007). It was decided to incorporate the supports of the earlier bridge (dating from 1898) on a basis of the following considerations (Lazić, 1998):

- detailed inspection and surveying carried out in 1996 revealed no settlement or inclination,
- a long period of consolidation (100 years),
- even though the new structure is much heavier (3x), this should not adversely affect the stress in the ground, as the weight of the foundation and the support is very large.

The column and abutments were constructed of cut stone filled with lean concrete and founded on 12-18 m deep caissons (Lazić, 1998). Fixed pot bearings (6000 kN) are installed on the central pier, while the pot bearings on the abutments (2000 kN) are movable in one direction (Lazić, 1998). Expansion joints KT-160 are installed at both abutments (Lazić, 1998). Damage observed includes settlement and damage to bridge embankment and asphalt layer just before the bridge, and damage to the bridge bearing and bearing pedestal on the column, as shown on **Figure 9.20**.

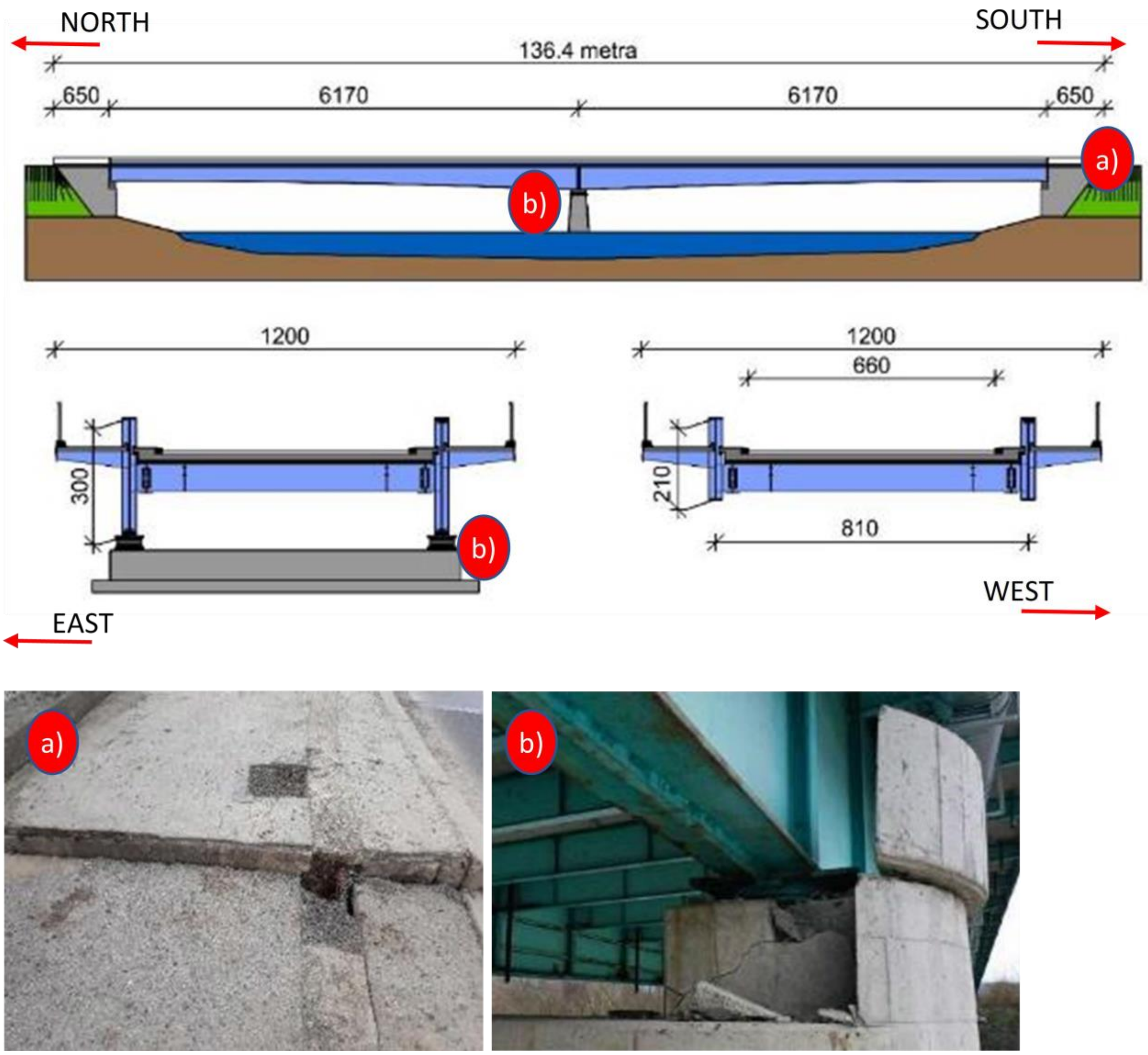

Figure 9.20 Brest Bridge damage indicated in longitudinal and cross-section of the bridge (from Radić et al., 2007): a) settlement of the sidewalk before the abutment, b) damage to the bearing pedestal on the column (right).

Old Bridge in Sisak

The Old Bridge in Sisak is an arch bridge across the Kupa river from 1934. A portion of its brick railing fell during the earthquake as illustrated in **Figure 9.21 (a&b)**. Some other railing portions were displaced (**Figure 9.21 c,d&e**), but according to an article (siscia.hr, 2018) they were damaged even before the earthquake. Some damage is visible in masonry above the arch, close to an abutment.

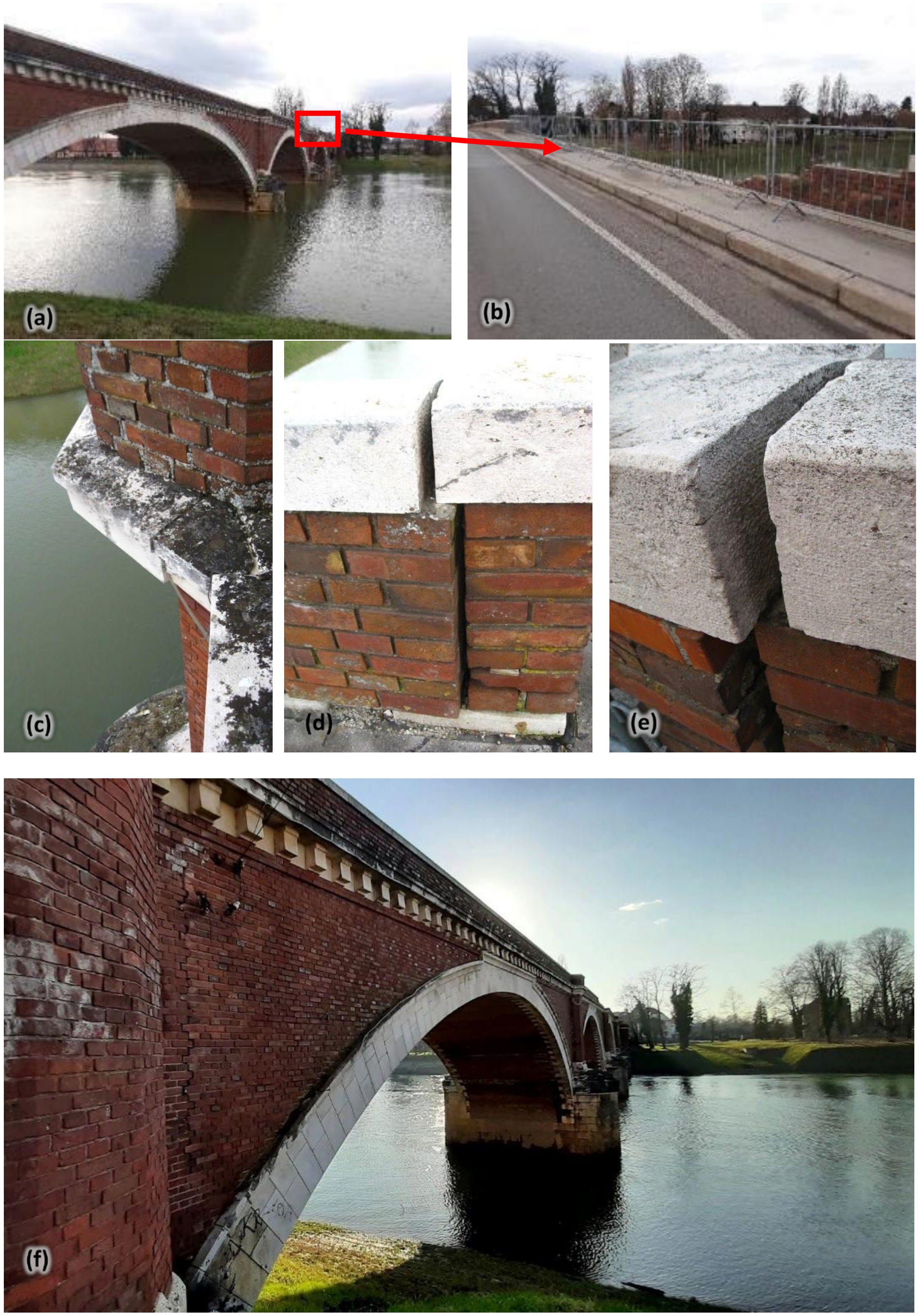

Figure 9.21 Damage to the pedestrian railing of the Old Bridge in Sisak: a (45.483N, 16.371E), b (45.4829N, 16.3705E), c (45.4829N, 16.3707E), d (45.4829N, 16.3707E), e (45.4830N, 16.3707E), f (45.4825N, 16.3692E).

References

Hrvatske ceste d.o.o. – Croatian Roads Ltd. (2021). *Izvješće o štetama od potresa u Sisačko-moslavačkoj županiji koji su se dogodili 28. i 29.12.2020*. (in Croatian; *Earthquake Petrinja 29 12 2021 GP HC_Road and bridge damage report*). Zagreb, Croatia.

dpreradus (2020) 'Obilazak mosta u Galdovu', SISAK.INFO, 17 May [online]. Available at: https://www.sisak.info/2020/05/17/obilazak-mosta-u-galdovu/ (Accessed: 4 February 2021)

Đuro Đaković Montaža (2020) *Reference - Mostovi*, Available at: http://www.ddmontaza.hr/data/source/file/2017_10_16%20Reference%20/4_2016%20Mostovi.pdf (Accessed 21 April 2021)

Lazić, D. (1998) Obnova mosta preko Kupe kod Bresta, *Ceste i mostovi,* 44(1-6), p.41-44

Marković, S. (2020) 'Završetak sanacije Galdovačkog mosta u Sisku', PORTAL53, 14 May [online]. Available at: http://portal53.hr/zavrsetak-sanacije-galdovackog-mosta-u-sisku/ (Accessed: 4 February 2021)

NHERI RAPID Facility (2021) GEER - Croatia, Galdovo Bridge Cyclone REGISTER 360 Registration Report

Novak, J. (1984) Naši mostovi – Most preko Save kod Galdova, Ceste i mostovi 30 (8), p.339-341

Radić, J., Žderić, Ž., Puž, G. (2007) Vrijeme rušenja, vrijeme građenja, Zagreb: Hrvatska sveučilišna naklada

Sisačko-moslavačka županija (2019) Obilazak mosta u Galdovu prije početka sanacije [Online]. Available at: https://www.smz.hr/6369-obilazak-mosta-u-galdovu-prije-pocetka-sanacije (Accessed: 4 February 2021)

Sisačko-moslavačka županija (n.d.). Natječaji i javni pozivi/smz/O županiji/Infrastruktura [Online]. Available at: https://www.smz.hr/natj/javni/details/133-javni-poziv-potpora-subvencija-za-organizirani-dolazak-turista (Accessed: 15 February 2021)

Urbane ideje d.o.o. (2018) Dokumentacija za nadmetanje Most Galdovo na državnoj cesti DC36 (Izvedbeni projekt sanacije), Samobor: Urbane ideje Ltd.

Županijska uprava za ceste Sisačko-moslavačke županije (n.d.). *Cestovna mreža Sisačko-moslavačke županije* [Online]. Available at: https://www.zuc-sk.hr/index.php/ceste (Accessed: 15 February 2021)

Željeznički projektni biro Ltd. (ŽPB). (2002). *Sanacija cestovnog mosta preko rijeke Kupe u Sisku na D-37. Čelična konstrukcija i ograda. Izvedbeni projekt broj ev*. 3088D/2002. Zagreb: Željeznički projektni biro Ltd.