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FIELD APPLICATION FOR ASSESSING THE DAMAGE AND USABILITY OF BRIDGES AFTER AN EARTHQUAKE

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Abstract

After the last two major earthquakes that shook northwestern Croatia in 2020, field inspections of structures were carried out according to a previously defined methodology, which was implemented through a software application. However, this methodology and application was limited only to typical (multi)storey buildings made of masonry and/or reinforced concrete. A similar approach is now being developed specifically for bridges to create a standardized and straightforward procedure for post-earthquake inspection process. The results of the inspection are entered via a mobile application interface and then uploaded to a central cloud database. This data is divided into three categories: (1) general information about the bridge, its traffic and geometry, information about the structural system, superstructure and substructure definition, information about bearings, expansion joints and equipment; (2) results of the inspection with damage classification grades associated to each bridge element, ranging from slight to moderate to heavy, all according to the proposed methodology; and (3) final assessment of the bridge's usability. The usability of the bridge is assessed as usable, temporarily unusable or unusable according to the previously identified and classified damage. An unusable bridge is to be closed for traffic due to critical structural damage, while a temporarily unusable bridge can further be restricted to a defined traffic speed or vehicle weight, or further inspection or immediate construction work may be recommended to prevent further damage. The benefits of such a bridge usability classification are particularly important in post-earthquake aftermath when search and rescue operations are carried out, demolition crews and heavy machinery are deployed, and mobile temporary housing units are transported. Furthermore, the central database with all the information collected can be used to manage and plan the repair and retrofitting of damaged bridges.

Keywords: bridge, earthquake, damage assessment, usability

1. Introduction – background and project intention

Croatia is a seismically very active area, as was proven by two major earthquakes that struck northwest of the country [1]. The first one was in March 2020 with the epicentre 10 km north of Zagreb with a magnitude of M_L=5.5 [2], and the second stronger one was in December 2020 with the epicentre 50 km southeast of Zagreb near the town of Petrinja with the magnitude of M_L=6.2 [3]. Both earthquakes caused severe structural damage to Zagreb city and nearby settlements, and throughout the whole Sisak-Moslavina County. Recorded structural damage ranged from severe damage including total collapse (about 11% of buildings) to light or moderate damage (65% of buildings) [4,5]. Both earthquakes caused damage to historical masonry and concrete residential buildings, reinforced concrete structures, but also to linear infrastructure (roads, bridges, pipelines) [6] and soil damage (landslides, liquefaction, sinkholes) [7]. After both earthquakes, teams of civil engineers were organized by a Civil Protection Authority and led by experts from the Faculty of Civil Engineering Zagreb to perform a rapid post-earthquake usability assessments. The assessment was carried out according to the methodology which comprised a five-level damage classification system and three-level usability labels [8].

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Problem that was identified during these actions was an inadequate official local and global government platform which would organise civil engineers, give them precise and consistent guidelines for inspection actions, and educate them for assessment procedures. Also, one of the major difficulties was an absence of a framework for collection and processing of gathered inspection data. All these problems were soon to be addressed and solved as the crisis management was established and greatly improved upon since then in the last four years. The post-earthquake inspection system is now well established, with clear procedures, educated engineer personnel rosters, data collection methodologies, digital application tools and cloud databases [9]. However, this framework is still limited to structures which include houses and multistorey buildings (residential or otherwise) with typical structural systems comprising masonry and reinforced concrete. Special engineering structures including bridges are still not covered by these inspection procedures, there are no guidelines, methodology, digital tools or database for collecting information. The post-earthquake rapid damage and usability assessment of bridges and other linear infrastructure during the last two earthquakes in Zagreb and Petrinja in 2020 was limited to an assessment aimed at decision making procedures which resulted in binary answers as to whether the bridge can continue to be operational. There were only a few exceptions where additional actions were prescribed concerning limitations in traffic speed and vehicle weight [10]. The assessment procedures back then did not include systematic gathering of information that would provide additional information about their seismic response or categorize the damage of structural and non-structural parts. Additional problems were recognized where insufficient data was available about the bridge previous state, so some of the damage could not be clearly associated with earthquake actions. Results and conclusions of these inspections were insufficient for later decision-making procedures, such as for the post-earthquake retrofit. There was no data about the urgency for the retrofit of each bridge, nor an estimate about the extent and severity of the damage. In order to get any usable information needed for retrofit projection plans, its financial estimate and funds application, additional inspections were required for each bridge, and for many of them these have not yet been carried out. For the others, there was clear evidence that not all the important damage was recognized during the first rapid post-earthquake inspection. Some of this damage did require immediate actions which were thus not timely performed. It is therefore also crucial that inspections are to be performed by civil engineers experienced in bridge design and maintenance and educated according to adopted assessment methodology.

Motivated by the benefits of the framework that was created for gathering and storing inspection data collected in post-earthquake rapid assessment of houses and buildings, a project was launched to create a similar framework for bridge inspections. In this paper current progress of this project will be presented, discussing some of the challenges of applying the same (or similar) approach as in building inspections. Nevertheless, when fully implemented, this assessment procedure and accompanying digital application and database will become a valuable part of post-earthquake crisis management process, and short-term bridge retrofit estimate.

2. Objectives and agenda

Purpose of the Croatian Centre for Earthquake Engineering is to create a system for organizing engineers in situations after earthquakes, based on their level of education and specific knowledge. Within this agenda, the main objective of this specific project is to establish a framework for conducting post-earthquake bridge inspections, performed by specialist bridge engineers, which would contribute to strengthening of the civil protection system in response to threats to public health and safety, and afterwards recovery and renewal. This objective will increase readiness in managing emergency disaster situations in terms of speed of response, allocation of human and other resources, assessment and reduction of risks, and mitigation of the short and long-term consequences of the disaster.

The secondary objective is to ensure the readiness of civil engineer personnel to perform post-earthquake bridge inspections with sufficient knowledge to recognize important damage that can compromise bridge usability and ultimately its statical and dynamical integrity.

The specific objective of the project is to establish a platform for conducting inspections of bridges after the effects of devastating earthquakes, using specific and standardized forms for the rapid inspection,

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according to standardized and clearly defined procedures. These forms are to be included in the mobile application that can be used on tablets and smartphones directly in the field, and gathered information can be uploaded to the cloud database. The applied model is based on the experiences from 2020, from previous post-earthquake building inspections, but this time adjusted for bridges, taking into account all variations between different bridge types and their possible damage due to earthquake actions. It is important that a uniform methodology is adopted, so that the gathered information is consistent across whole database, to provide accurate overview of the damage. During the rapid bridge inspection, the main goal is to evaluate the possibility and conditions (type of traffic, vehicle weight, speed) for continuation of use of the bridge immediately after the earthquake. The condition of all bridge components is ascertained individually and an overall conclusion about the usability is given, with or without any limitations. Immediate actions can also be prescribed to ensure further usability and/or stability, and in extreme cases when the damage is excessive, full bridge closure can be ordered.

To summarize, all the specific project objectives can be assorted into the following categories:

- development of the standardized forms / application as a digital tool for the input of inspection data according to prescribed methodology,
- availability of a GIS cloud database for storing all relevant bridge information, gathered prior or during bridge inspection, used as a support for extracting needed bridge data during inspections, and inputting post-earthquake inspection conclusions, to be used for decision making process short-term immediately after the earthquake, and also for long-term strategic planning of retrofit,
- education of civil engineers in the specialty of bridge inspection and bridge usability assessment.

3. Previous work and foreign experience

After several strong earthquakes left many bridges in the USA damaged and collapsed, much of the funding and research [11] was dedicated to assessment procedures, retrofitting measures [12–14], design codes upgrades [15], and post-earthquake inspection protocols [16–18]. California implemented a digital web platform ShakeCast [19] which according to recorded ground motions automatically sends warnings about possible damage to certain bridges, calculated from database in which fragility curves are associated with each bridge. Several manuals and guidelines for post-earthquake inspections and assessment/evaluation have been made in the USA [16,17,20–22]. New Zealand published Bridge inspection and maintenance manual [23] which provides a special chapter with guidelines, techniques and procedures for inspections of seismic damage. Several publications by California Department of Transportation (Caltrans) have been issued in order to develop a standard procedure and training program for assessment of earthquake damage. One such publication is a Visual Catalogue of Reinforced Concrete Bridge Damage [24] which documents and classifies earthquake damage into 5 levels and gives guidelines on how to recognize them. Post-earthquake bridge inspection manual from Oklahoma Department of Transportation [16] is intended to prepare and define qualifications for inspection personnel, establish inspection procedures, illustrate typical earthquake damage and provide standard post-earthquake inspection forms. Post-earthquake Bridge Inspection Guidelines for New York State [17] present a course of action in response to an earthquake to assess damage to highway bridge system, in which a bridge can be closed, restricted for traffic, or flagged for further investigation, repair or retrofit. Post-Earthquake Investigation Team (PEQIT) Manual [21] from Caltrans gathers information about the performance of bridges to evaluate current design and retrofit procedures. Post-earthquake investigation field manual for the state of Kentucky [22] provides a rapid and efficient method of inspecting damaged bridges with evaluation forms to be filled out electronically, and damage classified as red, orange and green label. Handbook for the post-earthquake safety evaluation of bridges and roads [20] also uses 3 colour label tags (red, yellow and green) and 2 level inspection protocol for post-earthquake response assessment.

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4. Post-earthquake rapid assessment of bridges

Following a strong earthquake, it is necessary to perform a rapid assessment of traffic infrastructure to detect any significant damage that compromises its usability. Unsafe bridges are to be closed for traffic to avoid their total collapse and casualties. Traffic should be rerouted to bridges that have been assessed as safe. For moderately damaged bridges, where some damage is detected on their structural parts, a limitation of traffic (weight and speed) can be defined. If necessary, temporary emergency immediate measures (supports, stabilization, etc.) for ensuring their further load bearing capacity and integrity are to be prescribed. Priority in rapid assessment is to be given to bridges which are considered as seismically most vulnerable, especially if they are positioned on the traffic routes with high traffic intensity. Certain bridges can also be prioritized if they are to be used for transportation of intervention vehicles such as heavy demolition machinery, construction vehicles, fire vehicles, supply vehicles, temporary housing transportation vehicles, etc. These are the bridges that are located on traffic routes leading directly to the areas most affected by earthquake. Inspection teams must be experienced in bridge design, knowledgeable in all the various bridge types and structural systems, special bridge elements and seismic devices, properly educated so they know which elements are most likely to be damaged during an earthquake, and to be able to identify any critical damage, assessing further usability of the bridge.

Results of the post-earthquake rapid inspections are to be recorded in form fields which are divided into 3 main parts: bridge information, detected damage information and assessment of usability. All inspection information is to be stored in the cloud database, which will be populated with information and accessible in real time, both in-field to all inspection teams, and in-office for coordination and planning purposes. Each bridge can be allocated for inspection to certain team, which will be visible via GIS location mapping. In this manner, an overview of all the bridges in the affected area will show which bridges are to be inspected and by whom, and for which bridges the inspection is already finished. After inspection is finished, awarded usability assessment label will also be visible on a GIS map.

4.1. Bridge information

Bridge information contains data unrelated to earthquake damage. Figure 1 shows all the different categories of this information, relating to bridge location, traffic type, traffic route, geometry, bridge type, structural system, substructure and superstructure elements, foundations, bearings and seismic devices, bridge equipment, etc. Not all of these are mandatory to fill in, some categories can have just one selection, and some multiple selections. Certain choices can 'lock' or 'open' subsequent categories or inputs, so that the total number of fields is scalable depending on the information already provided.

Most of the information shown in Fig. 1 can be chosen from predefined choices which are presented in the application when selecting each input. To distinguish between these choices, and choose the correct ones, an accompanying manual is to be issued in which all the definitions are given regarding all the inputs. It is important that all the inspection teams abide by the same definitions when making input choices, so that all the information stored in the database is consistent for all the inspected bridges.

All bridge information can be collected during inspection itself, or certain fields can be populated automatically if they are already available in the cloud database. It would certainly be beneficial if the database already contains all (or some) relevant bridge information, for bridges for which such information can be gathered from the design documentation, unrelated to the inspection itself. If present, this information would greatly reduce the time needed for inspection, but it would also provide invaluable help to the inspection engineers by informing them about all the details relevant to bridge seismic behaviour, which are not always accessibly available or reachable in visual inspections. The process of entering this information in the database prior to the inspection is still to be discussed, namely finding an appropriate model for doing it, and companies/personnel responsible for completing this task.

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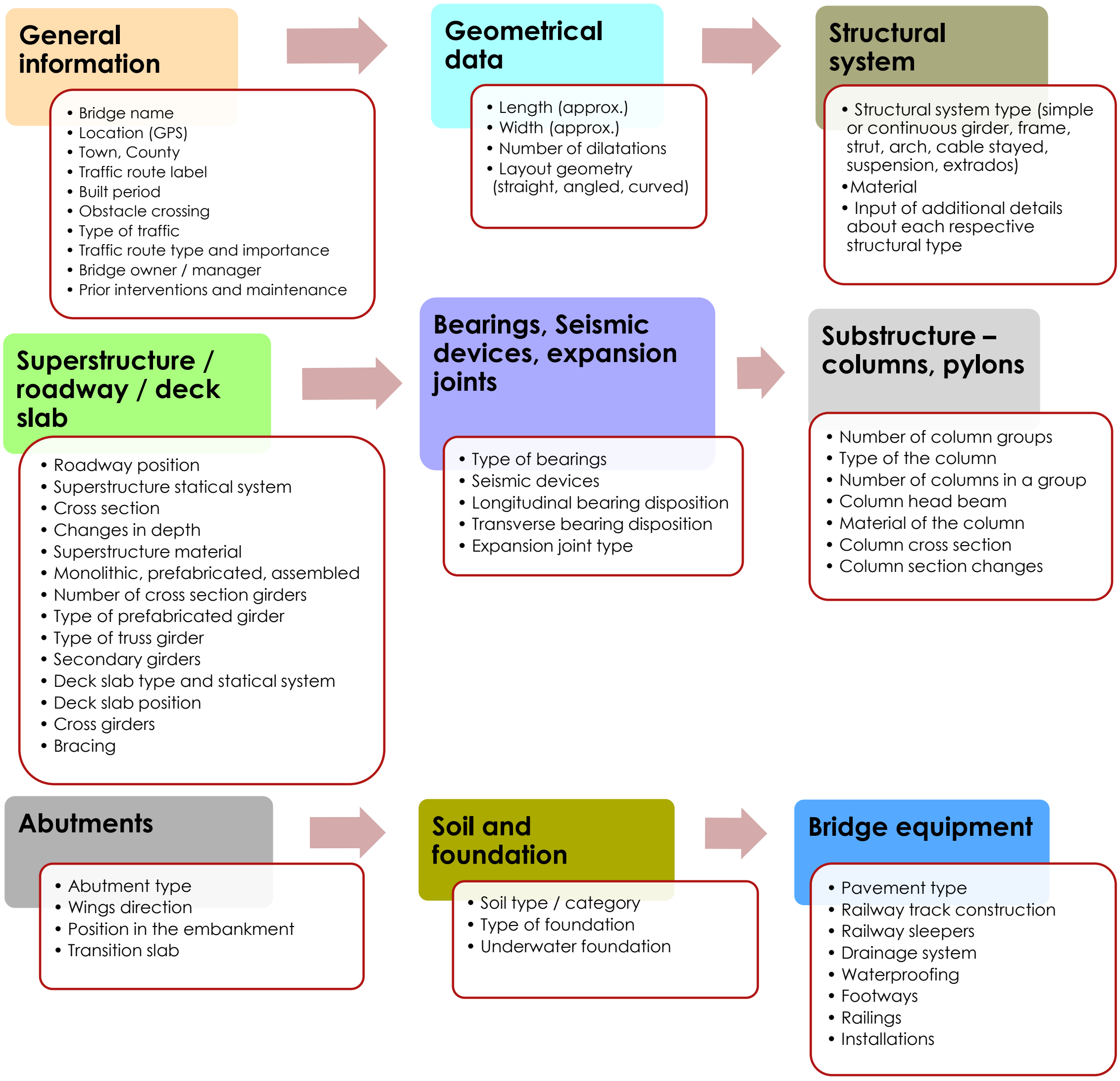

Figure 1. Categories of input of bridge information

4.2. Detected damage information

After bridge information input is completed, inspection team must input damage information. Damage is input according to the bridge elements which can be grouped into soil, foundation and substructure damage, superstructure damage, and equipment damage including seismic devices, bearings and expansion joints. Most of the damage is to be classified into one of 4 categories: 1. very heavy damage; 2. moderate damage; 3. slight damage; or 4. no damage. For some damage (related to soil and foundations), only a binary choice of present/not present is possible.

4.2.1. Soil, foundation and substructure damage

Soil damage or failure is to be detected according to the following occurrences: embankment fracture, liquefaction, landslide activation, settlements, foundation soil fracture, and fault opening. Some of these do not necessarily occur during the earthquake but can also occur in the following days and weeks after the earthquake. If at least some indications for these occurrences are detected, they must be photographed, measured and monitored regularly in the next days/weeks to detect possible progress of damage. Liquefaction can be detected if a dense mixture of sand and water is present on the surface around the bridge foundations [25]. It can result in foundation settlements than can lead to loss of

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stability of the abutments, columns and ultimately superstructure (Fig. 2 a.). Occurrence of liquefaction is only recorded as present/not present. Fractures in the bridge embankments can cause damage to traffic surface and/or loss of stability of bridge abutments (rotation or sliding) (Fig. 2 b.). Fracture of embankment can be recorded as present with visible movements, present with only visible cracks, or not present. Landslide activation can be very dangerous for the bridge integrity (Fig. 2 c.), since it can occur suddenly, with very little warning, so any indication of possible landslide is to be recorded as present with no further damage classification. Fault opening can also cause total bridge collapse (Fig. 2 d.), so if detected, bridge should be closed for traffic with no need for damage classification. Foundation settlements can be the consequence of any previously mentioned occurrences, or any other earthquake related soil damage. Differential settlements are especially dangerous since they can lead to superstructure deflections and rotations (Fig. 2 e.), with possible total loss of support. Most uneven settlements due to earthquake occur between bridge superstructure and embankment behind the abutment with damage to the traffic surface. In this case, limitations to traffic speed should be given accordingly. Foundation settlements are to be recorded during inspection with their approximate movement value in these categories: >15 cm (bridge unusable), 5-15 cm, <5 cm (bridge temporary unusable with at least traffic speed limitation), and none (bridge usable). Foundation soil fracture will occur if the vertical load due to seismic event increased above soil load bearing capacity. This is not often the case, unless liquefaction or uneven settlements also occurs, in which case heavy damage will be present. If such a case of soil fracture is detected, bridge should be closed for traffic.

Damage to the foundation structures due to earthquake can occur on foundation slabs and/or piles if they are present. Most common failure of foundations are pile overload, shear failure of foundation slab or piles, column-foundation anchorage reinforcement failure, pile pullout, reinforcement flexural yielding in foundation plates [17]. Most damage is almost impossible to detect during the rapid assessment since these elements are rarely visible. Only parts of the foundation which are above the ground can be inspected. Nevertheless, if possible, for foundation elements damage can be recorded with 4-degree classification, as stated previously, with an additional option if the state of damage is not visible/unknown. Heavy damage is to be input if foundation failure is detected (Fig. 2 f.), moderate damage for large cracks, and slight damage for small cracks.

Figure 2. Examples of soil damage: a. liquefaction [25]; b. embankment fracture [26]; c. landslide [27]; d. bridge collapse due to fault 7 m upthrust [28]; e. column settlements causing superstructure deflections [26]; f. heavy damage to foundation piles [29]

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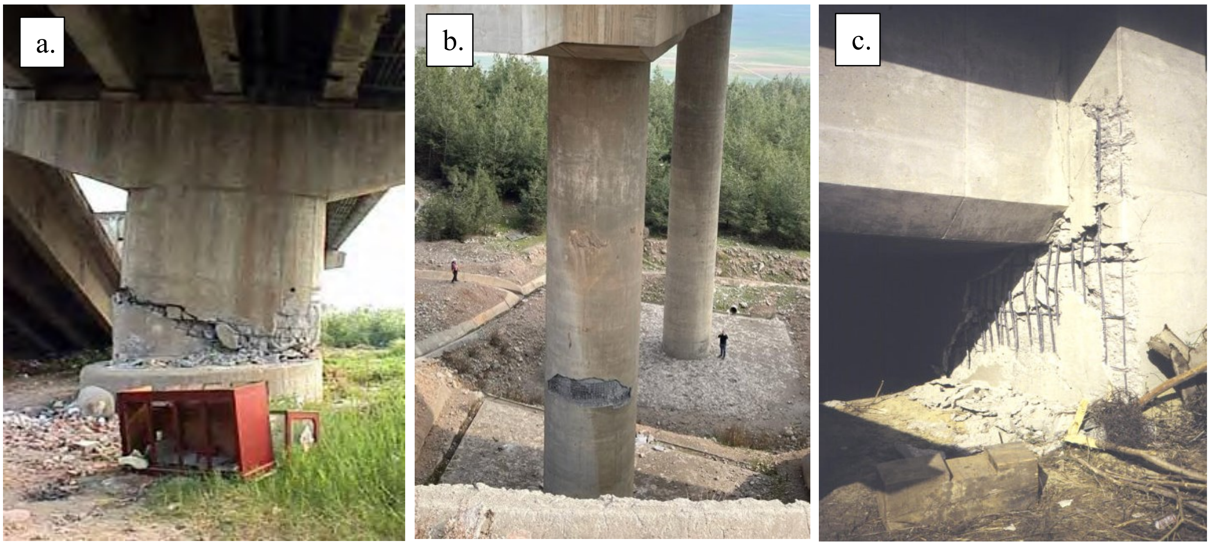

Figure 3. Substructure damage: a. heavy damage to column due to shear failure [16]; b. moderate flexural damage to column [30]; c. moderate damage to abutment wall – cracking and delamination of concrete [20]

Substructure damage is divided into abutment and column (if columns are present) damage. Abutment damage is further divided into categories of abutments movements or rotations, damage to abutment walls and side walls, and damage to wings. Movements or rotations of abutments can be caused by previously mentioned soil or foundation damage. Heavy damage is associated with discontinuation of traffic surface, and with danger of loss of support for superstructure. For moderate damage settlements up to 15 cm can be tolerated. Total failure of abutment wall when superstructure has detached from the wall or bearings is heavy damage, while some cracking (0.5 to 1 mm crack width) and concrete delamination in abutment wall can be classified as moderate damage (Fig. 3 c.). Wing wall failure can lead to landslide of embankment behind the abutment wall, so if this damage is detected, it is to be regarded as heavy damage. Most damage to abutment side walls occur due to impact of the superstructure during earthquake movements, so this damage is often heavy, but it has little consequence to overall usability of the bridge. Typical column earthquake damage comprises shear or flexural damage, compression failure with reinforcement buckling, or any of these combined. For each of these damage types, a damage level can be input. Heavy damage from flexure is considered when yielding of reinforcement occurs, with large concrete crushing and cracking, and detachment of reinforcement from concrete. Moderate flexural damage is considered when concrete compressive strength is reached and delamination of concrete cover occurs (Fig 3 b.). Concrete shear failure occurs when inclined sliding surface has fully developed, with visible slip along this surface, causing reinforcement bending/failure and cracking/crushing of concrete (Fig 3 a.). Smaller shear cracks up to 0.5-2 mm are considered as moderate column shear damage. If steel columns are present, heavy damage is considered when local buckling of the section elements or global buckling of the whole column is present. Damage to column head beams can also be input. Most of this damage occurs due to superstructure impacts, or due to head beam acting as a frame beam element together with the column for lateral earthquake loads.

4.2.2. Superstructure damage

Superstructure can suffer damage due to excessive movements, main girder horizontal or vertical impact into other substructure elements, girder excessive bending or shear force, transverse bending of girders due to lateral seismic action, torsional effects on horizontal or cross bracings, reaction from fixed bearings or seismic devices, etc. Main danger as a consequence of seismic movement of superstructure is slippage of girders from their support which results in total collapse of superstructure. Any damage in which a superstructure has moved excessively, so that any aftershock or other load could cause loss of stability of superstructure, must be classified as heavy and bridge must be closed (Fig 4 a.).

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Figure 4. Superstructure damage: a. excessive movement [18]; b. heavy damage to main girder due to impact in the seismic block and horizontal bending [30]; c. heavy damage – failure of horizontal bracing [31]

For movements that caused damage in traffic surface or deck slab, but adequate support still exists, damage can be classified as moderate (usually this is true for movements up to 15 cm). Heavy damage to main girders is considered when large deflection of plastic deformations are visible (Fig. 4 b.), large cracking due to bending, buckling of steel plates, excessive shear cracking and crushing of concrete in the area of prestressed cables anchorages. If the damage is localized, mainly caused by the impact of the girder into other element, and the bearing capacity of the girder is unchanged, then the damage can be considered moderate. Damage to horizontal or vertical bracings can be substantial since these elements are engaged during horizontal earthquake actions. This can lead to their failure (Fig. 3 c.), fracture or buckling. It is necessary to evaluate if remaining horizontal stabilization is adequate for such a superstructure in case of an aftershock and classify damage as heavy or moderate accordingly.

4.2.3. Bearings, seismic devices, expansion joints and other equipment damage

Damage to bearings and seismic devices are most common types of damage since these elements are engaged during earthquake the most. Causes of damage are excessive displacements of movable or elastomeric bearings, failure of fixed or tension bearings due to excessive earthquake reactions (Fig. 5 a.), inadequate anchorage to substructure or superstructure (Fig 5 b.), excessive in-plane rotations of the superstructure, especially for skewed bridges, lack of boundary movement limitation elements. Heavy damage includes fracture of the bearing body (within neoprene or otherwise), large movements (surpassing the bearing height) and lateral dislocations from the substructure support surface, fracture of the anchorage system, permanent excessive deformations, and damper liquid leakage. Expansion joints usually suffer damage from excessive movements, more than 15 cm can be considered heavy damage, 2.5-15 cm moderate damage, and <2.5 cm slight damage. Traffic speed limit should be set if the traffic surface surrounding the expansion joint is damaged. Bridge equipment damage is to be recorded for drainage, insulation, traffic surface, railings, cornice, installation ducts, etc. This damage will most likely not influence usability assessment of the bridge, except in some cases impose traffic speed limitation.

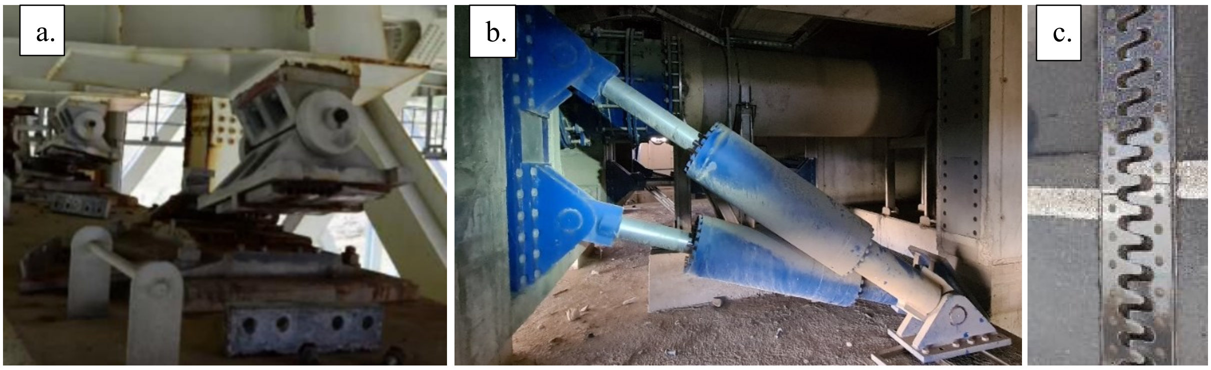

Figure 5. a. Fixed bearing failure [32]; b. Dampers detachment; c. Transverse movement of expansion joint [33]

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4.3. Assessment of usability

Final step of the rapid post-earthquake inspection is to evaluate all the detected damage and assess further usability of the bridge. This assessment is based on the professional judgement of the inspection team, whose members must be sufficiently educated to make such assessment. If there is a heavy structural damage, bridge must be closed for all traffic, and bridge is labelled as 'unusable' (red label). Heavy structural damage is such a damage that threatens the structural integrity of the bridge, or if some parts of the bridge have already collapsed. Most commonly heavy damage may result in sudden bridge collapse by effects of bearing slippage, foundation soil landslide or settlement, column turnover or column shear failure (Fig. 6) [10]. Excessive opening of plastic joints in the column or superstructure sections may also result in collapse if structural system becomes a mechanism. If indications of any of these types of damage have been detected, it is recommended that the bridge is closed for traffic.

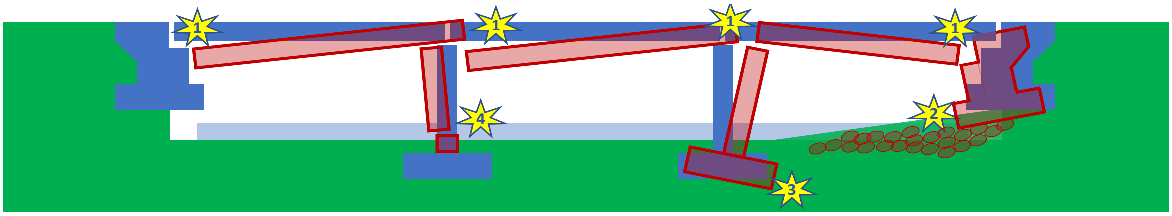

Figure 6. Most common earthquake types of bridge sudden collapses (any or all can occur): 1—bearing slippage; 2—abutment foundation soil landslide; 3—column turnover; 4—column shear failure [10]

If a moderate structural damage is detected, with no risk of total bridge collapse, a designation of 'temporary unusable' is to be assigned in the assessment (yellow label). This assessment leads to further recommendations and/or actions that are required. In any case, for this assessment a detail inspection is required to fully assess the extent of damage, which is to be carried out afterwards. In the meantime, bridge may stay open for traffic if either certain temporary immediate short-term measures are undertaken, or limitations in traffic loads and/or speed are imposed. Short-term measures, if required, must be described in the report in an unambiguous way. They may include temporary supports, stabilization of landslides, repairing of the damage in the traffic surface, alternative traffic regulation – closure of some traffic lanes, etc. Limitation of traffic may be input by closing the bridge for certain types of heavy vehicles, by defining maximum axle load, or by limiting vehicle speed (Fig. 7). For bridges where no damage is detected, or only non-structural damage which does not impair traffic safety, an assessment 'usable' can be assigned (green label), and bridge can be continued for traffic use without any limitations.

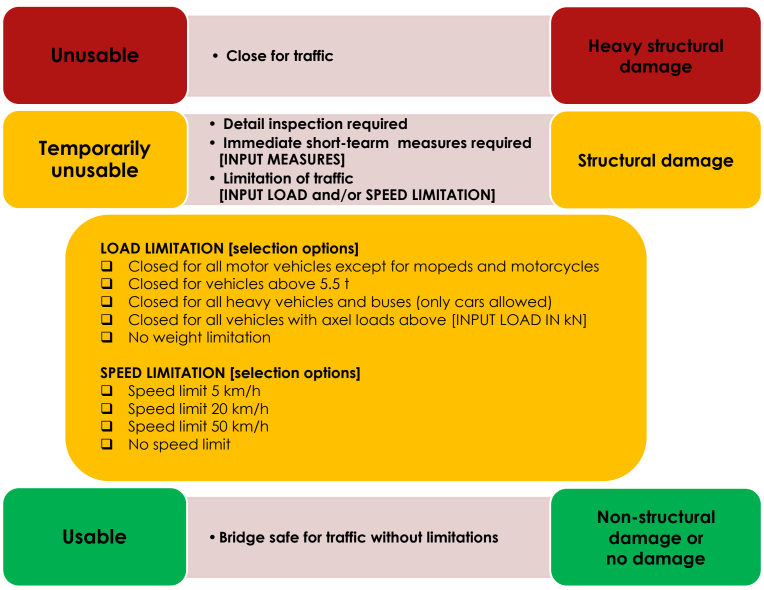

Figure 7. Assessment of usability – labels and additional options / actions

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5. Mobile field application

All the bridge information, damage information, and usability assessment, as discussed in section 4, is to be input during inspection using dedicated mobile application that can be downloaded to mobile phones or tablets. Application is currently in development (Fig. 8) (for now is only available in Croatian language). Input fields in the application can be numerical, textual, or multiple-choice selections where either only one or multiple choices can be selected at the same time. For certain choices, other sections may appear or disappear (for example if the number of bridge columns is zero, then no further information about column types and their damage is asked for), thus reducing the size of the questionnaire to only that information which is relevant and existent for the bridge in question. Photos are to be uploaded from the phone/tablet camera for the damage that is relevant for the final assessment. Mobile application is directly connected to cloud database and live GIS map so assessment information can be accessed from all users in real time. This gives an overview of the usability of all the bridges in the affected area and helps in coordination of teams for further inspections of remaining bridges.

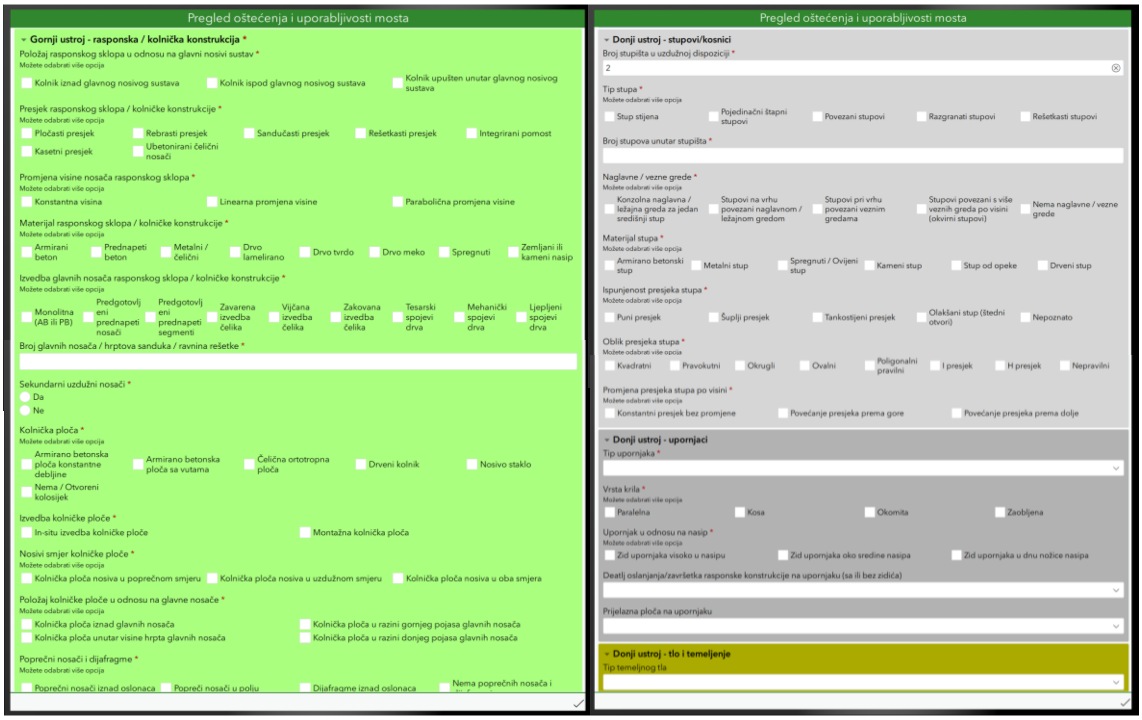

Figure 8. Screenshots of mobile application for assessment inspections (in development, in Croatian)

6. Beneficial parties / users

This project will be beneficial to a wide range of users which are identified as following: general population; Civil protection agency; Ministry of physical planning, construction and state assets; Ministry of the interior; Government of Republic of Croatia (including other state affair bodies); regional and local governments; infrastructure and bridge management and maintenance companies and institutions. General population will benefit from gaining information about the possibility of using safe traffic routes after the earthquake, which is especially important in case of evacuation and/or allocation events. Civil protection agency will have implemented practices for an earthquake event using specialist engineers educated for bridge inspection. It will also have better management of the crisis, for allocating and directing emergency intervention services and their equipment (fireman, search and rescue teams, medical units, heavy machinery transportation and allocation, temporary housing units' transportation, food and water supply, etc.), knowing which bridges are safe to use, and to which extent. If necessary and when possible, immediate measures could be performed on some bridges according to the inspection conclusions, making them short term usable again and mitigating the danger of their total

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collapse, therefore simplifying their afterwords reconstruction. Ministry of physical planning, construction and state assets will gain basis for making key strategic decisions to decrease earthquake consequences. Ministry of the interior will have access to timely information for efficient crisis management which includes traffic regulation and ensured public safety. Government of Republic of Croatia is expected to enhance actions of civil protection agencies, homeland security and strategic planning. Regional and local governments are expected to benefit from gaining basis for taking emergency measures to reduce earthquake consequences, as well as gaining information about the state of their infrastructure network. Infrastructure and bridge management and maintenance companies and institutions will have insight in the usability of their bridges and the demand for retrofit and maintenance work. Along all these parties, benefits are also expected for the civil engineering community, by establishing and educating specialists capable of post-earthquake bridge inspections.

7. Conclusion

An inspection protocol and methodology for post-earthquake rapid assessment of bridges is currently being developed. Field mobile application, cloud database and GIS will enable rapid response, consistent assessment results, ensured public safety, better crisis management and retrofit planning.

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