Land Subsidence Effects on Bridges in the World

Morteza Nateqi, Hamed Niroumand

***Abstract*—** Subsidence is one of the most hazardous phenomena that occur like a sudden sinking or gradual settling of Earth's surface. This dangerous phenomenon is directly influenced by subsurface movements of materials. Due to human activities, the common causes of subsidence are depressuring of underground reservoirs. But it can also be caused by natural reasons; for example: increased flooding (caused by loss of land elevation), withdrawal of fluids (groundwater or petroleum) or resources. Nowadays subsidence is considered a big problem in the world. There are a lot of counties in the world that are under the effects of subsidence. It has often occurred by reason of massive ground-water withdrawal and causes many damages. This article indicates that bridges are structures which have recently been threatened by subsidence. Sometimes, it is difficult to make up the damages but sometimes they are not possible to be made up. Therefore, subsidence and its implications on the Earth are considered two important issues that must be studied before the occurrence of subsidence and damage of monumental bridges. Considering the situation, this problem may occur in different amounts of depth and width. Studies on subsidence prove that the rate of danger increases with increase in its measurements. In this article, bridges that have been damaged due to subsidence have been introduced in detail. It is necessary to study about different kinds of hazards and their effects on the world. In that case, the number of hazards will be decreased or they will not be accomplished anyway.

***Keywords*—** bridges, damages, effects, subsidence, world

I. Introduction

LAND subsidence is a global calamity which have almost occurred in all kinds of regions all around the world. Through land subsidence, sublayers of the ground get started to settle gradually. In fact, as sub ground materials move, land surface starts to be changed. Land surface deformation may happen vertically in a gradual way that in this case, this situation is called "Land Subsidence" [1].

Several factors cause the sub ground materials to move. Some of them are because of natural phenomena; such as inundation flooding. Whereas the others are due to vast human activities; For instance, depressuring of underground reservoirs, excessive extraction of petroleum or ground water and extensive land use changes [1], [2].

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II. Investigation of Some Subsided Bridges

There are some bridges in different regions all over the world which have been constructed in hazardous conditions. It is really important to assess the conditions before the construction of a bridge. In order to prevent the bridges from subsiding or even reduce the number of damages, it is required to obtain some information about the bridge which is going to be constructed and the condition it has. Hereby, it is going to assess the situation some bridges have.

Indonesia is an area which is suffering from land subsidence and its effects. By use of some techniques such as repeated leveling measurements, GPS surveys and InSAR measurements, it was distinguished more than 2 meters of subsidence is taking place in Semarang, Indonesia. Land subsidence has caused many problems in this vast archipelago, such as sea inundation, expansion of flooding areas, cracking on buildings, sinking on the bridges and even dikes [3] as shown in fig. 1.

Fig. 1 Sea inundation (a), cracking on the buildings (b), sinking on the bridges (c) and dikes (d) due to land subsidence occurred in Semarang and Jakarta, Indonesia [3]

Land subsidence has also influenced on the quality of life in Jakarta, Indonesia. By mostly linear pattern of land subsidence in these areas, it is predicted that the impact especially on infrastructures are probably will getting worse ahead, too [3]. Fig. 2 can show the trend of this threatening situation in Jakarta and Semarang. Thus, it will be so easier to predict the prospective situation by considering this issue in order to protect the area from subsidence.

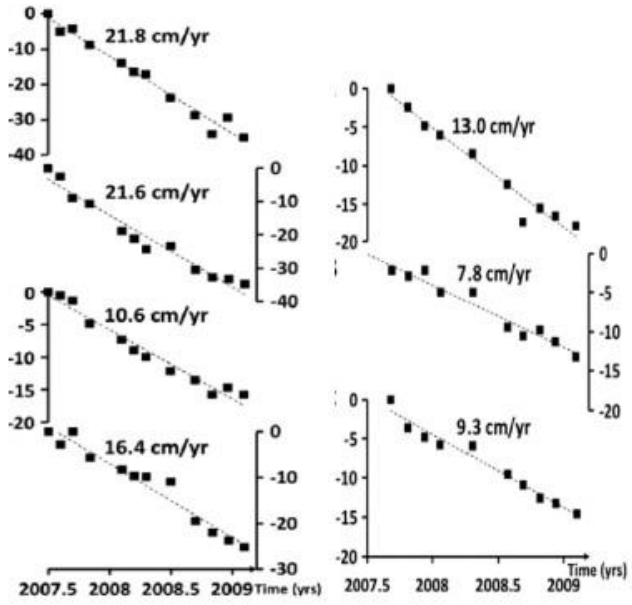

Fig. 2 Mostly linear trend of land subsidence in Indonesia [3]

Under global warming, as the main factor of many current global calamities, land surface has been facing some challenges which is particularly considered as a threatening situation to permafrost, as one of the sensitive kind of lands to temperature change in the world. Indeed, the most serious problem to roadbed stability is that they get started to subside due to thawing of the permafrost [4]. Before such a phenomenon happens, it has been needed to protect the roadbed, foundation soil or any other layers which might be threatened by thawing of ice contents. They can be easily protected by use of different geotextiles and geomembranes, such as segmental block faced G.R.S. (Geo synthetic reinforced soil). This will help the bridges that have been constructed in permafrost regions not subside. Furthermore, it would be helpful to consider the percentage of underlying ice content during the bridge designing as well.

The relationship between the subsidence and the requisite factors during the bridge designing needs to be thoroughly clarified. Some researchers have pointed out that the total subsidence amount on the sunny slopes is higher than that on the shady ones, according to the general statistics [4] as shown in fig. 3.

By assessing the relationship between the subsidence amount and ground temperature along with the ice content, it is easy to understand that the average subsidence in a high temperature permafrost is mainly higher than that in a low temperature one wherever the bridge is located in sunny or shady slopes [4] visible in fig. 4. In other words, even climate condition might influence on subsidence and its impacts. Bridge section along the Qinghai Tibet railway in China, which has been exposed to Land subsidence, is currently being intensified by climate changes.

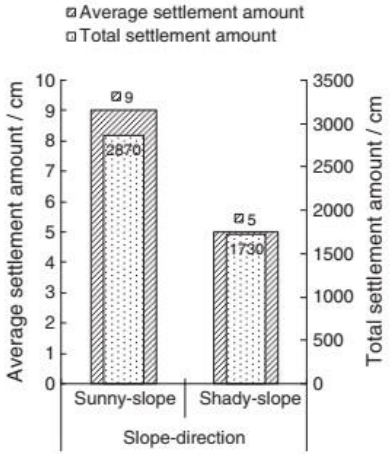

Fig. 3 Relations between the settlement and slope directions, according to general statistics [4]

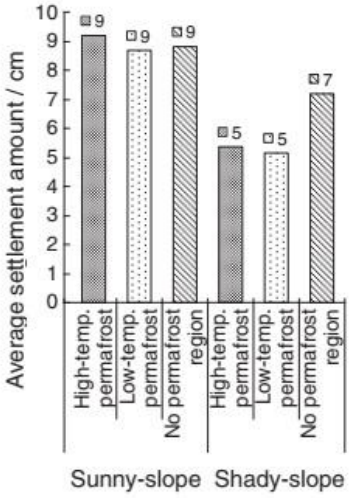

Fig. 4 Relations between the settlement and the ground temperature under the different slope directions, according to general statistics [4]

By assessing the historical subsidence in the San Joaquin Valley occurred by 1970, it turned out that several infrastructures and structures have been damaged or destroyed movingly. As an instance, Friant Kern Canal is one of such structures. 30 miles of this canal were influenced by subsidence in the Tulare Wasco area. Actually, parts of the canal subsided 7 cm/year during 1951-1975 (almost 5.5 feet). Not only the canal but also other structures over it were impacted by this gradual catastrophe [5]. In fact, subsidence and its implications on the Earth are considered two important issues that must be studied before the occurrence of subsidence and damage of monumental bridges.

In the other parts of San Juaquin Valley, Land Subsidence caused Outside Canal to settle and then be damaged. Thereby, Russell Avenue Bridge over this canal, in north of Mendota, was partly submerged [5]. The bridge is probably in a

tolerable situation but the continuous trend of land subsidence in this area must be considered. Usually, it would be really hard and time consuming to make the subsidence impacts up.

Fig. 5 The submerged Russell Avenue bridge over the Outside Canal, in north of Mendota, California [5]

To be more aware of calamities such as land subsidence, it is necessary to study about them in detail and consider some important factors as well. Damages that calamities impact, are such issues must be studied about.

III. LAND SUBSIDENCE DAMAGES TO BRIDGES

Subsidence is considered as one of the biggest problems in the world that might cause a lot of damages. Sometimes, it is neither economic nor easy to make the damages up; and sometimes it is not possible at all. Therefore, subsidence and its impacts are considered two important issues must be studied before they accomplish. On the other hand, land subsidence includes different amounts of depth and width. A subsidence with big measurements requires a big attention, too [6].

Land subsidence causes different kinds of damages. For instance, faults by length of almost 47 km (e.g. in Qal'eh Tasouj, East Azerbaijan, Iran) [7], tidal flooding (e.g. in Semarang, Indonesia) [3], Seasonal deformation (e.g. in the 40 km long Santa Ana Basin, Los Angeles, California, the United States of America) [8], prediction of land loss (e.g. in Southern New Jersey, Atlantic Area, New Jersey, the United States of America) [9], and Damages of walls, roads, homes and water lines (e.g. in Las Vegas valley, Nevada, the United States of America) [10].

Beside the damages were mentioned, it is noteworthy that sometimes infrastructures are subjected to destruction by occurrence of land subsidence. Bridges are one kind of essential structures which are usually designed around 1.5 meter or even more above the water level. But sometimes, land subsidence makes them slowly descending. Therefore, the water would easily touch or pass through the bridges floor. Figures 6 and 7 show the sinking bridges in Semarang and Jakarta respectively [3].

Fig. 6 Situation of two sinking bridges in Semarang, Indonesia [3]

Fig. 7 Situation of a sinking bridge in Jakarta, Indonesia [3]

It should be noted that land subsidence is not only the cause of environmental or social problems but particularly the economic ones as well. Economic damages, due to land subsidence, are significantly more noticeable than the other kinds.

In estimation of Roll (1967), Viets and others (1979) and Fowler (1981), land subsidence along the Santa Clara Valley caused the direct costs including repairing water wells which had been damaged during 1960-1965, building of storm sewers and pumping stations where waste fluids no longer flowed easily by gravity, building dikes to prevent flooding and raising bridges and roads. All costs totaled 756 million dollars, translated to 2013 [5].

IV. SOME WAYS TO STOP A BRIDGE FROM SUBSIDING

At least, there are ten bridges in Jakarta which might be slowly destroying by the water underneath in the near future. To lift bridges to a higher level is considered as a tolerate solution but the main problem is that many dollar should be spent for each. In Semarang, there are also five bridges which are passed by the water permanently now. The situation would be even worse during a rainy season. Thus for, in order to stop the water from passing through the bridges, some dikes have been built. However, land subsidence makes the bridges descending and even the built dikes cannot solve the problem then [3]. As a result, stronger decisions and more serious prosecutions are required in order to terminate this uncontrollable situation in Indonesia.

In order to stop a bridge being subsided, some items should have been investigated before; such as subsidence amount at the joint of the abutment, protection slope at two sides of the bridge, bridge orientation, embankment slope direction and roadbed structure. Subsoil types, values of ground ice content of permafrost and ground temperature are other items which must be immediately investigated [4].

As it was already mentioned, before the occurrence of land subsidence, it is needed to protect the roadbed, foundation soil or any other layers which might be threatened by thawing of ice contents by use of geotextiles and geomembranes; for instance, G.R.S. bridge abutments and piers.

G.R.S. bridge abutment is actually a G.R.S. mass which has been covered with segmental block facing. Therefore, it is titled G.R.S. which is short for segmental block faced geo synthetic reinforced soil. The facing acts as a construction aid and as a protective barrier. It typically offers little resistance in the structure. Thus, the reaction of a G.R.S. bridge abutment really differs from an abutment on a rigid foundation. G.R.S. mass along with the segmental facing act as a monolith which is considered as a massive foundation in a G.R.S. bridge abutment. Thereby, all the stresses have been transferred to the foundation soil due to the superstructure loads, are reduced. In addition, G.R.S. mass along with the abutment will subside together which causes the degree of a bump to be reduced at the end of the bridge [11].

Field tests have been dedicated that in case of performing G.R.S. bridge abutments and piers, there will be excellent performance characteristics and very high load carrying capacity for the bridge. It is so easier and more economic to construct such a bridge abutment than a conventional one (e.g. reinforced concrete gravity and semi gravity earth retaining wall). It has been investigated that in use of this kind of geomembranes, it is not required to use piles in order to reinforce the weak foundations. In that case, not only the costs but also bridge bumps often experienced at the ends of a bridge will be significantly reduced. As an example, a 7.6 meter bridge abutment and a bridge pier in the same height were constructed by Colorado Department of Transportation and the University of Colorado at Denver in 1996-1997. By investigations were done on these G.R.S. structures, it was clarified that their load carrying capacities were found to be higher than 200 k Pa (design pressure suggested by the FHWA Demo 82) [11].

It is considerable that performing each kind of the mentioned ways above absolutely depends on the situation and characteristics of the structure. Here is possible to name more and better ways which help an infrastructure or a structure not subside. But it should be also considered that preserving them from settlement will be better and more economic than rehabilitation of damaged or destroyed ones. So, it will be important to study about some factors causing land subsidence. Here are some of them have been explained below.

V. WHY A BRIDGE SUBSIDES

By compaction or consolidation of the bearing soil under the weight of the bridge, foundation subsidence may be caused. Before the construction of a bridge, foundation soil needs to be consolidated adequately. Amazingly, High traffic loads and scouring of the abutments are the other reasons of foundation subsidence. As the vehicle speed increases, effect of foundation subsidence on dynamic impact factors becomes significant. Thereby, road surface roughness may couple with the subsidence to increase the overall effect. This factor has considerable effect on the dynamic impact factors of bridges and vehicles [12].

Roadbed subsidence may also occur through insufficient compaction rolling, rain water erosion and the dynamic travelling load and so on. Roadbed structure, embankment height, geological and hydrological conditions are other factors which may influence on surface deformation or subsidence [4].

Subgrade soil type is another considerable factor that may let a bridge subsides. It has been investigated that the average subsidence amount in fine particle soil regions (e.g. silt, silty clay and clay regions) was significantly higher than others, whereas it was not observed any subsidence in sandstone and schist regions [4]. Fig. 8 indicates it very well.

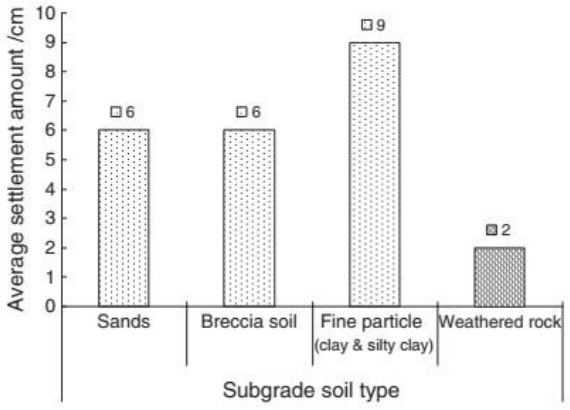

Fig. 8 Relations between the settlement and subgrade soil type, according to general statistics [4]

Sometimes underlying soils are hard to be compacted and consolidated due to limited space. Thus, the embankment height may impact on subsidence. Fig. 9 indicates that subsidence occurrence rate has increased logarithmically and gradually with the elevation of the embankment height [4].

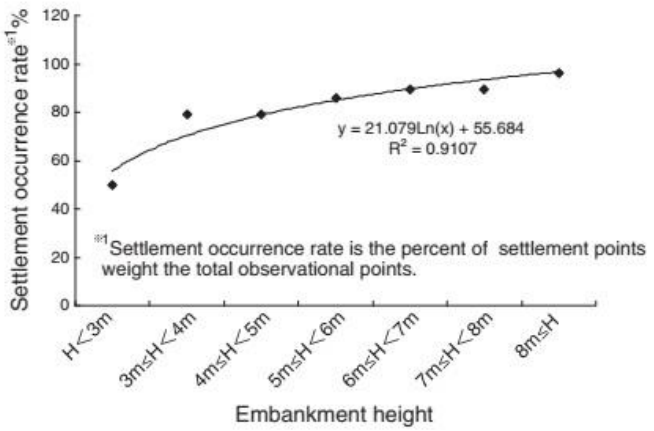

Fig. 8 Changes of settlement rate with the embankment height, according to general statistics [4]

As another factor causing land subsidence, it is clear that when the temperature increases, the bearing capacity of the frozen soil decreases [4]. This issue should be absolutely noticed during a bridge designing in low temperature regions such as a permafrost. In other words, one way to protect a bridge situated in such a location from subsidence is to protect the frozen foundation soil from being thawed.

As underlying permafrost temperature increases or even partly melts, the heat absorbing difference under the influence of slopes intensifies the subsidence, whereas the gravity and dynamic loads are the other dominant factors causing this kind of gradual calamity [4].

VI. Conclusion

Inundation flooding, depressuring of underground reservoirs, excessive extraction of petroleum or ground water and extensive land use changes are considered as consequences of sub ground materials movements. Through them, land surface starts to be changed and causes the land to subside. By occurrence of this gradual and "silent" phenomenon, many problems would appear that might affect different structures on the ground, even the important ones; such as bridges. This essential issue must not be disregarded and it is important to prevent the bridges from subsiding or at least reduce the number of damages. Anyway, it is required to obtain some information about the bridge which is going to be constructed and the condition it has. Because it will be so easier to predict the future situation and protect the area from subsidence.

Thawing of ice contents, insufficient consolidation, elevation of embankment height and improper kind of subsoil are such factors which threaten roadbed or foundation soil and subsequently the bridge. However, performance of geotextiles or geomembranes (e.g. G.R.S. bridge abutments or piers) in permafrost and construction of retaining walls or dikes are approaches can help bridges be safer.

Land subsidence and its impacts are considered as complicated issues which must be studied in detail. In order to stop a structure e.g. a bridge (especially monumental one) from subsiding and then damaging, it is needed to assess some important issues; such as occurrence of land subsidence, its impacts on structures or infrastructures, its causes and considering the ways help the threatened structure not subside. With the aid of comprehensive studies, experts are responsible to keep on. Land subsidence might happen anywhere all around the world due to any reason; consequently, before construction or even designing, assessing the situation is essentially recommended as soon as it is possible.

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