Formation of bridge end bumps due to settlement at bridge approaches

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Abstract. The problem of bridge bump has been a major issue for decades. Over the years, a lot of studies have been conducted by various agencies and professionals to investigate and pinpoint the cause of this phenomenon. Majority of researchers agreed that the major cause of the formation of bridge bump is the differential settlement of soil between bridge abutment and bridge approach. However, the exact cause of the settlement may vary depending on the site condition. Some of the causes of settlement were discussed in this paper which includes deformation of embankment fill, deformation of foundation soil, poor drainage system in and around the bridge abutment and poor design and construction practices. Besides that, current practices and new development of mitigation and rehabilitation methods were also discussed in this paper. This paper reviews the factors that contribute to the formation of bridge bump while also identifying the available methods that was used to eradicate this problem.

1. Introduction

Bridge structure is a multi-functional and highly-efficient structure built to cater services which may be highways, railway traffic, pedestrian footpath, public utilities or other kinds of services and to transfer the load from these services to the foundations at ground level. A bridge in general consists of few main components such as the superstructure (beams and diaphragms) and substructure (crossheads, columns, foundations, etc.). Due to the importance of the bridge to the society, each component of this structure must be designed with great precision by highly trained professionals. However, there is one component of the bridge which designers or engineers alike seem to put less emphasis on during design stage, due to its size and importance compared to other components, which is the bridge approach. Bridge approach is the interface where the road pavement meets the bridge. The main function of bridge approach is to provide an even level of transition for travelling vehicles from highway tarmacs to bridge structures and vice versa (Saride and Puppala, 2009). Nonetheless, settlement or deformation that occurs at bridge approach region relative to bridge decks usually leads to formation of bump on the road surface. This particular ‘bump’ formed at the end of the bridge could cause extensive damage to the bridge decks, endangering the motorists due to reduced steering control, tarnish public perception of the transportation agency’s image and inconvenience to the road users due to constant delays during rehabilitation process of the affected lanes (Hopkins and Deen 1969). Hence, the design of bridge approach must be considered as important as the design of other bridge components. A
proper planning and astute design concept should be adopted to alleviate the problem as it could affect various entities. Figure 1 shows the illustration of bridge approach and the abutment.

![Figure 1. Illustration of bridge approach and bridge abutment (White et al. 2005).](image)

Over the years, great number of researches has been done by various agencies and professionals all over the world to study and pinpoint the causes of the bridge bump formation and ways to mitigate or solve it entirely (Ha, Seo, and Briaud 2002; Dupont and Allen 2002; Puppala et al. 2009; Saride and Puppala 2009). This paper will delve deeper into this subject by identifying the mechanism and causes of the bump formation, reviewing the existing mitigation method currently used in the industry and also discovering new development in the mitigation and rehabilitation methods.

2. Bridge bump formation and contributing factors

The formation of bump at bridge approach has been a major issue for decades. Based on previous studies, majority of researchers agreed that the primary reason that contributes to the formation of this bump is the differential settlement of soil at the bridge approach. However, the causes of this differential settlement may vary as it is purely site specific and therefore could be more complex than it is initially thought. This subtopic will discuss further on the causes of differential settlement at bridge approaches. Figure 2 shows the illustration of settlement at bridge approach.

![Figure 2. Illustration of settlement at bridge approach (Chen and Abu-Farsakh 2016).](image)
2.1. DEFORMATION OF EMBANKMENT FILL/FOUNDATION

To allow the roadway to meet the elevation of the bridge, bridge approaches in general are constructed on an embankment fill. Most of the time the material used for the embankment fill mainly consists of soil which was known to settle over time especially those under the roadway and have to endure traffic load. As the soil consolidated and settled, this would lower the elevation of the embankment while the elevation of the bridge remained the same. This relative difference of elevation between embankment and the bridge leads to the formation of bump at the road-bridge interface. Besides that, material of embankment fill should be resistant to slope failures and lateral displacements that would lower the embankment elevation even further (Dupont and Allen 2002).

Ha et. al. (2002) conducted a study to investigate the formation of bump at bridge end. The study was done by distributing questionnaires to 25 districts of Texas Department of Transportation while also conducting a detailed investigation on the condition of two bridges in Houston, Texas. Based on the results obtained from the distributed questionnaires, it was found that the most common reason causing bump formation at bridge end in Texas is the settlement of the embankment fill and later followed by the erosion of the soil fill. Furthermore, based on the investigation at the two bridges, the researchers observed that the significant bump formed was caused by weak soil at the bridge approach. The data from this site investigation revealed that since it is more exposed to water, the soil near abutment has a higher water content compared to the soil away from the abutment which would lead to lower soil strength and higher soil compressibility that could cause the bump.

Whenever an embankment is constructed, it will be built on top of soil foundation. The materials used for the foundation usually came from the existing soil excavated at the site. Hence, the foundation itself would also be susceptible to differential settlement over time. Even if settlement did not occur completely in the embankment fill, the foundation soil beneath it could experience differential settlement due to traffic loads at the surface and dead load from self-weight of the embankment (Dupont and Allen 2002; Wahls 1990). As a result, there would be a difference in elevation between the embankment and the bridge abutment which would cause the formation of bump at the road-bridge interface.

A detailed research was done by Luna et. al. (2004) to evaluate the bridge approach slab performance and design in the state of Missouri, United States. Surveys were conducted and handed out to resident engineers and transportation officials of several states within the USA to find out the severity of the bridge settlement problems in their respective states. The outcome of the survey has shown that at least 15% of the recently constructed approach slab exhibits signs of distress and in need of remediation. Detailed investigations through site observations and numerical analysis were also carried out at two bridge sites in Missouri where bump formation at bridge approach has been detected. Bump formation at one of the bridges was speculated to happen due to the settlement of foundation soils and fill placement. Extensive soil report at this particular bridge revealed that the foundation soil consists of soft compressible soil layers. The results of the numerical analysis have shown that settlement had occurred at this bridge and this bodes well with findings from site observations and soil report.

2.2. Poor drainage

In few cases, poorly designed or poorly maintained drainage system could be a contributing factor that leads to differential settlement at bridge abutment. Whenever the drainage system failed to direct the surface runoff away from the abutment or embankment area, the water could infiltrate through the cracks and fault and into the soil fill behind the abutment. Water content of the soil will increase and directly lowering the bearing capacity of the soil. As a result, this would induce the settlement of soil behind the abutment resulting in the decrease in elevation of bridge approach.

Water infiltration into the bridge approach could also cause severe subsurface erosion and loss of fill material behind the abutment resulting in void development beneath the approach pavement (Saride and Puppala, 2009). Besides that, the runaway surface runoff also had the potential to erode
the side slopes at abutment which could cause a localized movement of backfill in and around the abutment affecting the elevation of the bridge approach (Dupont and Allen 2002).

2.3. POOR DESIGN AND CONSTRUCTION PRACTICES

Various studies have shown that most of the time, differential settlement of bridge approach happened simply due to poor design and construction practices (Hopkins & Deen, 1969; Ovi et. al., 2014; Saride et al., 2009; Seawsirikul et. al., 2015). Design and construction issues were not thoroughly addressed before, during and after construction would cause severe settlement of the bridge approach. Issues ranging from the improper or incomplete compaction of backfill, usage of unsuitable material for backfill, unsuitable type of abutment proposed, unsealed expansion joint at road-bridge interface, lack of maintenance at soil slope and RS wall of abutment or simply because the bridge approach was not constructed according to design. All this issue must be addressed properly in order to eliminate the factor that leads to differential settlement at bridge approach.

Kramer and Sajer (1991) reported this exact issue in the site investigation done at several bridges in Washington, United States. All the bridges selected were built without any approach slab on a relatively steady foundation soil and incompressible embankment backfill. During the investigation it has been found that majority of these bridges exhibits the some distress or bump at the bridge approach even though by right the settlement of soil should not happen due to the nature of the soil at site. However, further investigation beneath the pavement surface revealed that voids were formed below the corbel area of the abutment wall. The design of the corbel that projected from the abutment created an area where it is difficult to perform proper soil compaction. The voids then would cause displacement of soil particles and further settlement of embankment which would lead to the formation of bump. Figure 3 shows the formation of void below the corbel as reported by Kramer and Sajer (1991).

![Figure 3. Formation of void below corbel (Kramer and Sajer 1991).](image)

In addition to that, Yasrobi et al. (2016) also investigated this phenomenon in a detailed by performing thorough literature review to examine the outcome of researches from 12 states in United States while also conducting a nationwide survey in 28 states. The results of the literature review and the surveys were then compared and evaluated to produce a comprehensive conclusion. Yasrobi et al. (2016) revealed from the nationwide survey in 28 states that the most common cause of differential settlement at bridge approach is due to poor construction practices. The survey also revealed that the amount of approach settlement could be reduced by performing in situ tests to control backfill compaction. Some recommendations for mitigation methods were made based on this study which
includes improvements or modifications to the slab design, revising the current construction requirements of approach slab and proper maintenance of the drainage system behind the abutment.

3. Current practices of mitigation/rehabilitation

3.1. Approach slabs
The most common method used in the mitigation of bridge bump is the placement of approach slab beneath the pavement at bridge approach. The approach slab made up of high strength concrete and reinforced with steel acts as an intermediate bridge to span a part of the embankment directly behind the abutment. This method is more common due to the ease to design and construct while providing a smooth transition from the road pavement to the bridge surfacing. There are two types of slab commonly used in the industry which are approach slab on ground and approach slab on piles. Figure 4 shows a typical arrangement of approach slab on ground and approach slab on piles.

Figure 4. Typical arrangement of approach slab on ground and on piles (Seawsirikul et. al. 2015).

Seawsirikul et. al. (2015) conducted a study on the effectiveness of approach slab on piles in mitigating the differential settlement that cause the bridge bump. In the study, two bridges in Bangkok, Klong Song Bridge and Klong Bang Ta Nai Bridge, were selected as the ideal subject for investigation. Klong Song Bridge was designed with approach slab on ground while Klong Bang Ta Nai Bridge was designed with approach slab on piles. Field investigations were carried out at several locations within the bridge sites and settlement analyses was performed by utilizing Terzaghi’s one dimensional consolidation theory and elastic theory. The results of the study revealed that by comparing the settlement phenomenon at these two bridges, approach slab on piles is more effective in reducing the settlement. However, differential settlement still takes place at the location where the pile tip is resting on soft soil and stiff soil layers.

On the other hand, Zhang (2016) conducted a research to identify the parameters that have the most influence to the formation of bridge bump. It was done based on the collection of historic data related to inspection and maintenance of bridge approaches in Kentucky, United States. The important parameters discovered during the research includes geographic regions, bridge approach age, average daily traffic, the use of approach slabs and the depth of the foundation soil. The results of the research also revealed that the use of approach slabs have the ability to improve the performance of bridge approach by reducing the amount of settlement that leads to the formation of bridge bump.

On top of that, Hassona et. al. (2018) also conducted a detailed study of differential settlement by developing 2D finite element model with PLAXIS software and comparing the theoretical results with the actual field measurement at two bridges within El-Minia Governate, Egypt. The study found that there was a correlation and good agreement between the theoretical model and field observation regarding the soil movement or settlement due to the traffic loads at these two sites. The result has shown that the use of transition slab or also known as approach slab on ground at the bridge approach
actually reduced the settlements as it distributes settlement between each end of the slabs. However, this method only reduced the settlement instead of eliminating the settlement for good as it is impossible due to the fact that there are a lot of other complex factors that could lead to the occurrence of settlement such as the development of void beneath the slab due to soil erosion.

3.2. Asphalt patching/overlaying
Another common practice used in mitigation of bridge bump is the asphalt patching and overlaying. These two methods are the easiest and the most economical method used by most of the road agencies in the world. However these methods are only applied after settlement had occurred. When a bump developed at the bridge end, an asphalt wedge can be placed to smoothen the vertical transition and thus eliminating the bump entirely. Asphalt overlaying on the other hand can be relatively costly compared to application of asphalt wedges. This is due to the fact that it requires more labor and materials as the pavement needed to be milled over a certain distance along the bridge approach and the asphalt pavement is placed to smooth the transition. Dupont and Allen (2001) reported in a survey that most agencies agreed that this method nonetheless should only be applied as a temporary fix that could only last for a range of between months to few short years due to high impact loads received by the asphalt wedges and recurring settlement that could happened due to the additional dead load from the overlaying of new asphalt layer.

3.3. Mud-jacking
As the settlement occurred, a void would develop beneath the existing approach slab. In order to eradicate this problem, the method of mud-jacking can be applied. The process of mud-jacking involves injecting the stabilizing material such as asphaltic-aggregate, sand, foam or grout to fill in the void beneath the slab. This injected material could provide support to the slab and preventing total failure of the slab. But, this process can be expensive, messy, having mixed success rate and could bring other problem at hand. Hopkins and Deen (1969) reported that the use of mud-jacking to raise the slab could be detrimental to the slab itself because this procedure had the possibility to induce cracking and thus making the slab susceptible to water infiltration leading to more settlement, freezing and thawing and further deterioration of slabs. Hopkins and Deen (1969) also reported that out of 195 mud-jacked approach slab examined in 1964, almost 80 percent of the slab were cracked.

3.4. Replacement of approach slab
When excessive settlement of bridge approach is too severe, the approach slab might fail completely and needed to be replaced. This procedure should be opted as the last resort since it is the most costly and tedious out of the other options. A lot of labor, materials and equipment costs must be considered beforehand. Furthermore, the traffic at the affected area would be interrupted since some section of the bridge needs to be closed during the repair work.

4. New development in mitigation/rehabilitation methods
Current methods of mitigation have been found to be mostly ineffective in eradicating the problem of settlement at bridge approach. However, researches and studies are always ongoing and discovery of new methods are made on a consistent basis. This subtopic will discuss further on some of the new developments in mitigation and rehabilitation methods of bridge bump.

4.1. Geosynthetic-reinforced soil (grs) as embankment backfill
The practice of utilizing geosynthetic-reinforced soil in the construction of embankment at bridge abutment can be considered as relatively new. In this method, Helwany et. al. (2007) explained that geosynthetics were placed in layers within the backfill of embankment in order to reinforce the granular backfill soil resulting in stiffer backfill mass. Helwany et. al. (2007) also reported that the advantages of using GRS are it is cost effective, easy to construct, has good seismic performance and
able to tolerate lateral deformation without compromising the structural strength. An illustration of abutment utilizing GRS backfill is shown in Figure 5.

![Illustration of GRS abutment](image)

**Figure 5.** Illustration of GRS abutment (Helwany, Koutnik, and Ghorbanpoor 2007).

In another study, Helwany et al. (2003) investigated the potential of GRS abutments to reduce settlement at bridge approach by using finite element method of analysis through computer program DACSAR. According to the result of the analyses, it can be seen that the behavior of the foundation soil consisting of a range from dense sand to medium clay had a significant effect on the GRS bridge abutment. The performance of the GRS abutment when placed above clay foundation was significantly better than those placed above granular foundation soil. In conclusion, the study indicated that the utilization of GRS abutment was actually an effective method to diminish differential settlement between the abutment and bridge approach.

4.2. Lightweight fill / flowable fill

Utilizing lightweight fill as a backfill material in abutment is one the ways to reduce settlement. This type of material has less weight compared to the conventional backfill. By reducing the weight of the backfill the static load due to the embankment backfill would be reduced significantly. This in turn would cause less settlement to the foundation soil beneath the embankment. However, Wahls (1990) stated that unless the lightweight fill used has high strength and stiffness with low compressibility, the improved performance of the foundation under static load of embankment would be obsolete. Wahls (1990) also stated that material with high bulk density has a higher potential in mitigating the settlement and stability problems of the bridge approach. Materials such as low-density lightweight concrete, expanded clay shale and expanded polystyrene have been frequently used in the industry as an alternative to normal soil backfill.

Yenigalla (2011) conducted a study on the utilization of expanded clay and shale (ECS) as embankment backfill material on a bridge site in Arlington, Texas. One of the purposes of the study was to develop and establish a design chart to design embankments using the ECS. This was done by validating the results obtained from finite element method (FEM) model with the site monitored data of previous research. The study has found that the usage of ECS as backfill material could reduce the amount of settlement at embankment. Nevertheless, the effectiveness of the material is highly dependent on other factors such as the height if embankment, subgrade thickness and its compression characteristics.

On the other hand, the use of flowable fill in construction of embankment could reduce settlement through different mechanism. Flowable fill are self- compacting which means that this backfill material is compacted by gravity. Typically, granular soil and water were mixed in a concrete mixer and dumped into the area at the back of abutment call backfill prism. As the water drains, the backfill would be compacted by gravity. The self-compacting property of this flowable fill is particularly
useful due to the fact that compacted soil has lesser tendency to settle thus reducing the settlement that could cause the formation of bridge bump.

4.3. Modified one-span approach slab
In addition to the current practice of designing approach slab by implementing a two-span slab, another new development has been discovered by using a different design approach. Seo (2003) conducted a study based on the new concept of using a one-span slab. In the this study, a new approach slab design was proposed by reviewing the mechanism that leads to the settlement of bridge approach, evaluating the performance of the current approach slab design in Houston by performing numerical analyses and conducting a smaller scale simulations of the newly proposed design using BEST (Bridge to Embankment Simulator of Transition). The new approach slab is 6m long with one span from the abutment to the sleeper slab and was designing to carry the traffic load with support on the soil only at both ends. The results of the study revealed that the new one-span approach slab produced a smaller bump in comparison with the current two-span approach slab.

4.4. Increasing flexural rigidity of approach slab
A recent study was conducted by Chen and Abu-Farsakh (2016) to propose a new design of approach slab. The new design required increasing the slab flexural rigidity while also utilizing the previously mentioned GRS abutment or in a simpler terms. The flexural rigidity of the slab was increased mainly by increasing reinforcement ratio and the slab thickness or in simple terms it was design bigger and stronger than the conventionally design slab. The study was conducted by comparing the performance of two different slab design constructed at opposite ends of Bayou Courtableau Bridge in Louisiana, USA. The results of the study showed that the bridge end with the new slab performed better as there was less settlement observed compared to the bridge end with the traditional slab design.

5. Conclusion
The formation of bridge bump is a complex problem which involves a lot of contributing factors. The interaction between the abutment, bridge approach, backfill soil and foundation soil are vital in determining the causes of the settlement that lead to the formation of bridge bump. However, the exact cause of the settlement is impossible to pinpoint as it is purely site specific. Different location might present a different problem and that is the beauty of this topic. A lot of methods are available to mitigate this problem but there is no exact way to determine which of these methods are the most practical. The process is still ongoing to find the best solution to be implemented. Researchers and professionals are hard at work and therefore will consistently come up with new ideas which can only benefit the industry in the long run.

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