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МОСТИ ТА ТУНЕЛІ: ТЕОРІЯ, ДОСЛІДЖЕННЯ, ПРАКТИКА

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ANALYSIS OF THE PROBLEMS OF SECTIONS WITH THE TRANSITIONAL RIGIDITY INDICATOR IN WORLD BRIDGING

Purpose. To analyze the problem of areas with a transitional stiffness on the approaches to the bridges based on the experience of European and American bridge-building. To find out the root causes and methods for detecting track defects in transitional stiffness zones. To propose a pilot model for the development of transitional stiffness areas based on the experience of developed countries in Europe. **Methodology.** Collection of data on the causes and nature of the occurrence of bumps on approaches to bridges based on the experience of specialists in the design, construction and operation of railway and highway bridges. Analysis of methods of arrangement of transition areas on approaches to bridges in European countries. **Results.** An analysis of the literary sources of developed countries of the world on the problem of the origin and methods of detection of bumps in areas with transitional stiffness on the approaches of bridges was performed. The results were collected on ways to identify problems in areas with transient stiffness and how to solve them. A model for mathematical and experimental studies was proposed. **Originality.** Scientific interest is that, despite the extensive experience of developed countries of the world, the Ukrainian norms still do not have a clear mechanism for identifying and characterizing problems of track geometry in sections with transitional stiffness. Thus, studying the experience of more advanced countries in the field helps to con-sider the problem more clearly and standardize its definition. **Practical value.** If proposed model of reinforcement of transition stiffness areas will be confirmed it allows to reduce the cost of maintaining of the track and to solve the problems of the transitional areas at the stage of bridge construction, that is, before its immediate occurrence.

Keywords: bridge; transitional stiffness; approaches; high-speed lines; bump

Introduction

Railway lines are investments with very long life. Today many tracks are over 100 years old. Of course, components have been exchanged during the years, but parts of the track might remain the same – especially the substructure. Typical lifetimes of for example rails are 30…60 years and turnouts 20…30 years (Sundquist, 2000). However, to ensure this long life a large amount of maintenance is necessary.

Railway industry meet a lot of problem in general, but the problems with the roadbed are one of the most difficult to solve because of their long-term solution and the great losses not so much in solving problems as in stopping or organizing of redirection of the movement.

Purpose

To analyze the problem areas with a transitional stiffness on the approaches to the bridges on the experience in European and American bridge-building and to pay attention to the importance of this issue in Ukraine.

Methodology

Transition zones are commonly defined as a region of the track in which there is an abrupt change of track stiffness (mainly in the vertical direction). Such a change of stiffness may cause an increment of interaction forces between the train and the track and consequently an acceleration of the degradation process, when a train is moving on it (Alejandro de Miguel Tejada, 2015).

The bump at the end of the bridge is not a new problem. Both the highways and railways face this problem. Although both of these industries share many of the same contributing factors that lead to the problem, the solutions that are used to solve it are quite different (Nicks, 2009).

Railway track will settle due to permanent deformation in different layers of the track. The problem arises when different sections of the track settle unevenly. In such a situation this phenomena is called differential settlement and it could seriously affect the value of train-track interaction forces.

Settlements of the track come mainly from three different sources:

– settlements of the embankments and the subgrade soils due to a consolidation process, including the secondary compression phenomena;

– settlements due to traffic loading;

– settlements due to the structural interaction. Settlements of ballasted track occurs mainly in two phases (Dahlberg, 2001):

- in a short-term, after tamping, the settlement is typically fast until the gaps between the ballast particles have been reduced and the ballast is consolidated;
- in a long-term, there is a slower phase with an almost linear relationship between settlement and time.

This phase is caused by several basic mechanisms of ballast and subgrade behaviour. These mechanisms can be divided in two main groups, depending on the mechanical behaviour of the layers. The first one, due to a densification of both the ballast and the subgrade soil and the second one due to an inelastic behaviour of the two mentioned layers: ballast and subgrade soil.

The bump at the end of the bridge is classified as a track geometry degradation problem. It occurs in the track transition zone located at the interface between the approach embankment and the bridge structure

The Federal Railroad Administration in 1993 (Federal Railroad Administration, 1993) estimated that there were about 101,000 railway bridges in the US (not including rapid-transit operations). This number has likely increased since that time. After reviewing the literature, however, it is unclear how many of these railway bridges are affected by the bump problem.

To close this gap, a survey of railroad professionals was conducted during the (Nicks, 2009) to determine the extent of the problem. Based on a similar highway survey conducted by Briaud James & Hoffman (1997), about 150,000 out of 600,000 US highway bridges (as of 1995), about 25 %, experienced problems. This percentage is expected to be higher for railways due to the much higher loading environment.

Based on the Association of American Railroads (AAR) 2008 Strategic Research Initiatives Plan, the cost of railway bridge transition repairs is estimated as $26 million per year ($16 million for steel bridges and $10 million for concrete bridges). This figure does not take into account the significant cost resulting from slow orders that railroads must impose in problem locations. A slow order is a speed restriction where trains must travel at slower-than-line speeds to operate safely. By comparison, the cost of repair for highway bridges has been estimated at $100 million per year (Seo, 2003). The expense is much higher for highway bridges than railway bridges. This is likely due to the total number of bridges in service.

As part of the work Nicks (2009), a survey has been conducted among 9 world railway organizations in the USA, Canada and Australia.

Based on the survey responses, the bump problem affects, on average, 51 % of railroad bridges. This is double the number of highway bridges that are affected. The typical bridge consists of an open bridge deck (with height less than or equal to 3.05 m) resting on a deep foundation (e.g. piles) with no skew. As a majority, the respondents did not know what type of soil is typically used as compacted fill or as foundation soil.

A tolerable bump has yet to be strictly defined in the railroad industry. Most companies rely on visual inspections rather than measurements in deciding when to fix the bump problem. The annual cost of maintenance for the affected bridges of each company, including both internal and contracted, is estimated at $23 million total. This represents an average cost for each railroad company of $2.55 million per year. Although the respondents do not see the bump as a major problem, it is a nuisance that leads to track degradation and increased maintenance costs. Among those surveyed, the typical bump size ranges from 0,6 to 10 cm with an average difference in elevation of 3,3 cm along the rail profile. The horizontal length over which the bump occurs also varies, ranging from 1,2 to 15 m with an average of approximately 5 m.

The common causes of the bump problem were evaluated by the survey respondents. Each respondent ranked a given contributing factor on a scale of 1 to 4, with 1 representing the "most common" and 4 representing "never a factor". The results are summarized in Table 1.

Table 1

Factors contributing to the formation of the bump

Ranking	Topic
1	Settlement of fill
1	Others: difference in track modulus at transition, poor surfacing, not tamping approach properly, poor maintenance practices by bridge and track forces
3	Poor drainage
3	Dynamic impact of cars
5	Poor compaction of ballast on fill
5	Differential settlement between bridge and fill
7	Poor joints
7	Bridge type
7	Poor fill material
10	Loss of fill by erosion
10	Abutment type
10	Settlement of natural soil under the fill
13	Too rigid a bridge foundation
14	Poor construction practices
14	Temperature cycle
16	Poor construction specifications
17	Settlement of natural soil under the bridge abutment
18	Lateral movement of the bridge abutment

Based on these results, the most common factors leading to the bump are settlement of the fill, differential track modulus, poor surfacing, improper tamping and poor maintenance practices. The least common were lateral movement of the bridge abutment, settlement of the natural soil under the bridge abutment and poor construction specifications.

The cases where the problem appears to be worse are when: the bridge is an open deck bridge, the bridge is made of concrete and has concrete ties, concrete approach ties are used and wet conditions are present. Conversely, the cases where the problem appears to be minimized are when: the bridge is a ballasted deck bridge, the bridge/approach location is well maintained and there is good drainage.

The second problem was the mechanism of determining the exact location and nature of the bump. There are many current detection methods used by companies to find the problem (Table 2).

Table 2

Current bump detection methods

Ranking	Topic
1	Visual inspection
2	Track geometry evaluation car
3	Complaints from user
4	Ridability (subjective)
5	Ridability (quantitative)
6	Ride quality accelerometers
7	Non-destructive tests (NDT)
Others	Measure track stiffness or use survey equipment

The most common is through visual inspection. Many bumps/dips are fairly shallow, however, so it may not be visually noticed until the problem is more severe. The track geometry evaluation car is another widely used method to measure and depict the rail profile. Since the car simulates the loading of an actual railcar on the track, the results are more accurate.

Complaints from the user and subjective ridability are similar to visual inspections. These types of methods provide companies the information that a bump exists and if it is relatively dangerous. The size and slope of the bump/dip, however, are not quantified.

To help quantify the effects of the bump, ride quality accelerometers are typically placed on a locomotive to measure the response of the car on the track. Locations with degradation, such as at the bridge transition zone, will be detected with these instruments. Non-destructive tests are rarely used to detect the problem.

Research in transition areas has attracted a great deal of interest in recent years. This is evidenced by the fact that some of the most important European railway construction projects have been designed with a view to these critical areas.

In view of the above information, it is very important to minimize the impact that a change in resistance causes on a dynamic track-rolling interaction.

Traditionally the more complex type of transition in European countries, occurs in bridges due to construction system, drainage system and selection of appropriate backfill materials.

Compaction should be done with thin layers of soil and abutments will be designed to resist compaction forces. Drainage system is a critical issue in which a special attention has to be paid. A good drainage system prevents material erosion and hydrostatic pressures that leads to a decrease in loading capacity of the structure. Moreover, the presence of water inside the transition zone may induce undesirables variations of volume if it is frozen at extremely low temperatures.

Overall, the most usual constructive solutions in transition zones for railway tracks can be found in Gallego, Sánchez-Cambronero, & Rivas (2012):

- technical block: backfill behind the abutment either with granular material treated with cement or materials of a high compression level;
- transition slab: A concrete slab directly connected to the abutment of the bridge;
- use of geosynthetics to achieve an abutment reinforced backfill;
- introduction of horizontal layers on a track formation of different materials;
- treatment of the track bed and sub-ballast with cement (Pshinko, Petrenko, Tiutkin, Andrieiev, Hubar, Ihnatenko & Markul, 2019).

Spanish specialists Paixao & Fortunato (2009) suggest interesting options to adopt in transition zones in order to mitigate the undesirable effects associated with these critical points of the railway track. Amongst other, solutions analyzed by the authors are:

- use of internal rails fixed to the sleepers;
- use of longer and heavier sleepers placed closer together, in transition zones;
- use of more flexible and tighter track elements.

The aim of using internal rails in transition zones is basically to increase the global stiffness of the transition.

Regarding to the use of longer sleepers with a shorter distance, this allows a better distribution of the loads transmitted by the train, mitigating the effect of hanging sleepers.

Adoption of more flexible elements, allows to absorb dynamic excitations, reduces the propagation of deterioration phenomenon along the transition area and consequently reduces the maintenance costs. Nowadays this type of elements are common in track construction and they can be found under the rails, under the sleepers or on the base of sub-ballast layer.

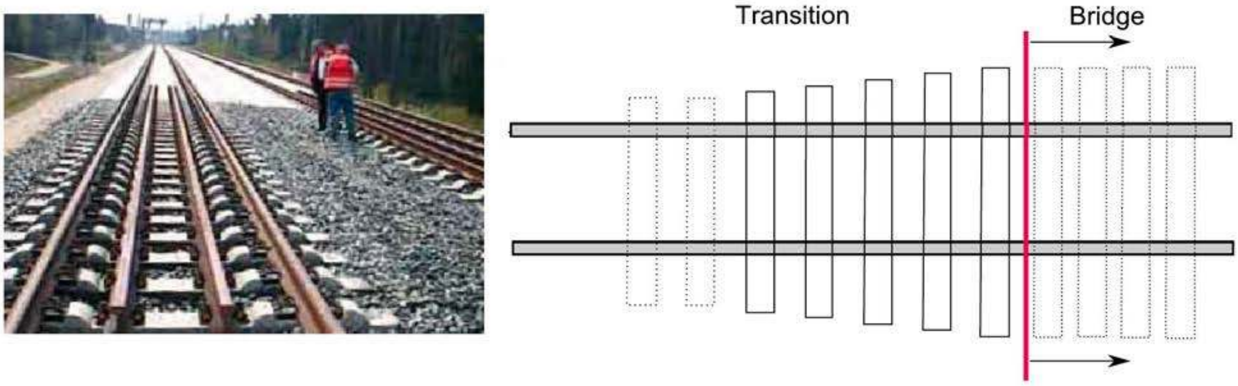

Fig. 1. Examples of solutions offered by Spanish engineers

The growing number of HSL, either already built or planned, implies a constant evolution of the transition zones morphology. This evolution follows a general trend in the most of European countries in which HSL exist. Some of the main construction features of the aforementioned trend are:

- Minimum length for the transition area of 20 m.
- Use of granular materials treated with cement in the backwalls of the abutments.
- Provision of drainage layers as a part of the backfill materials in the abutments.
- Treatment of different formation layers of the track with cement.

Regarding to complementary solutions for transition zones it is interesting to point out the state-of-the-art made by Ribeiro (2012), in which an interesting and a brief summary of the main complementary solutions that are used today in transition zones, is presented.

Since the development of high-speed lines is a promising area for railway development, let us consider the most commonly used solutions for transitional rigidity in Europe.

Configuration adopted by the Spanish Administrator ADIF is illustrated in Figure 2. In this case, the treated soil wedge presents an inclination 1:1. The top of this wedge is aligned with the bottom part of the sub-ballast layer and it has a length of 3 m. Between the treated soil wedge and the concrete structure, a vertical drainage system is placed.

The wedge of soil that does not have any treated material, its slope is 3:2 and it extends 20 m from the abutment location. The top of this layer is aligned with the bottom part of the formation layer.

The height of the technical blocks and embankments should be defined according to the characteristics of the foundation soils.

In the case of inadequate foundation soils, these should be removed and the base of the wedge should be properly treated.

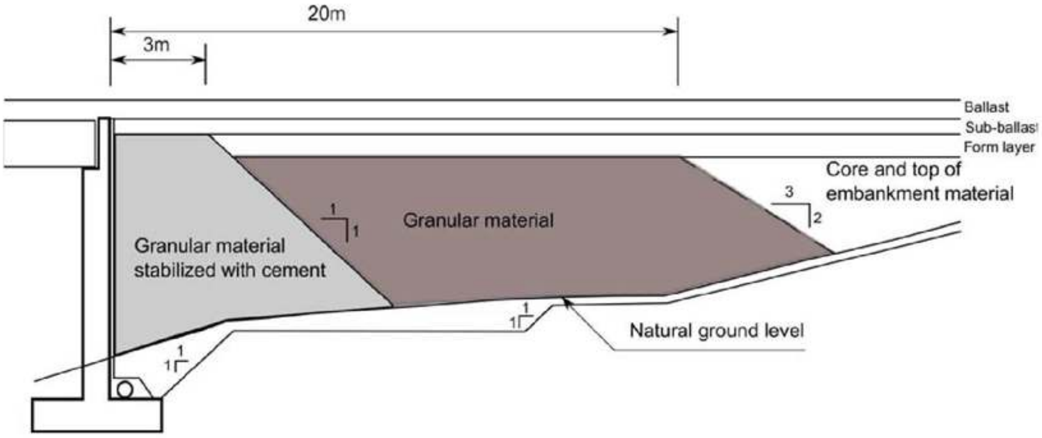

Fig. 2. Configuration designed by the Spanish administration ADIF

Figure 3 shows the solution adopted by the German Administrator. In this case, the solution is very similar to those provided by ADIF. The top of the treated soil wedge is placed approximately at 1 m from the down of the ballast layer and it has a length of at least 1.5 m.

The treated soil should have between 2.5 % and 3 % of cement content.

In this solution, the height of technical blocks is not directly specified but the foundation where they are placed on, should have deformability characteristics equal or greater than 45 MPa in the second phase of the plate load test.

Solution adopted by the French Administrator is depicted in Figure 4. This configuration corresponds to the case in which there is an open abutment solution and a height of the technical block higher than 10 m. Similar solutions are adopted in those cases in which there is a close abutment configuration or a culvert.

In this case, the treated soil wedge exhibits a height of 3 m, whereas the height of the technical block in the transition zone.

The width of this wedge will be of approximately1 m, on the top, and it has an inclination of 1:1. Furthermore, the cement content in it is 3 %.

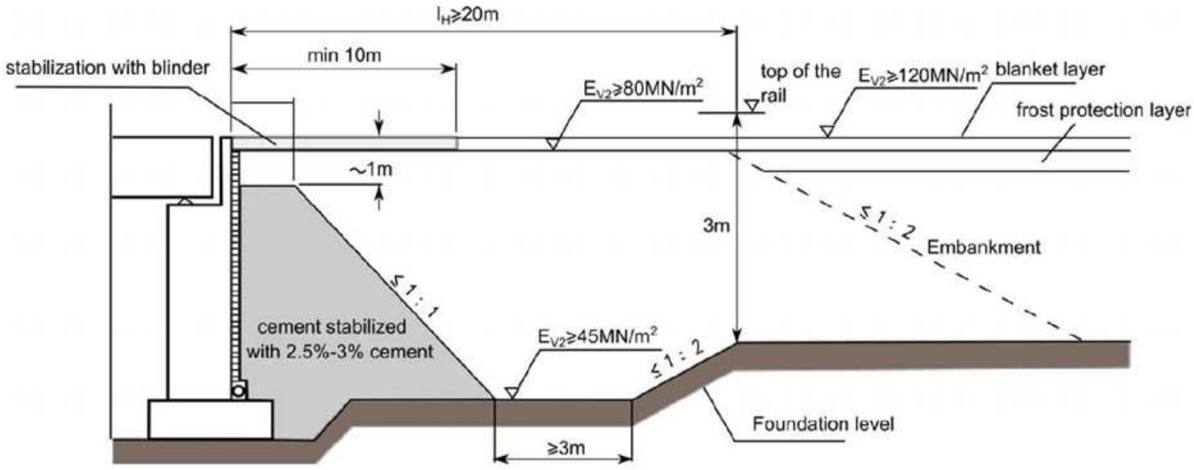

Fig. 3. Configuration designed by the German administration DB

The height of the wedge that does not have any treated soil and it is similar than the height of the technical block.

The length of this wedge, on the top part, is 5 m and it has an inclination 3:2 as it can be seen in Figure 4. As in the previous cases, the height of the technical block is not directly obtained, and it depends on the conditions of the foundation soil. If the above mentioned height is higher than 10 m, a foundation layer of select and well compacted material should be adopted.

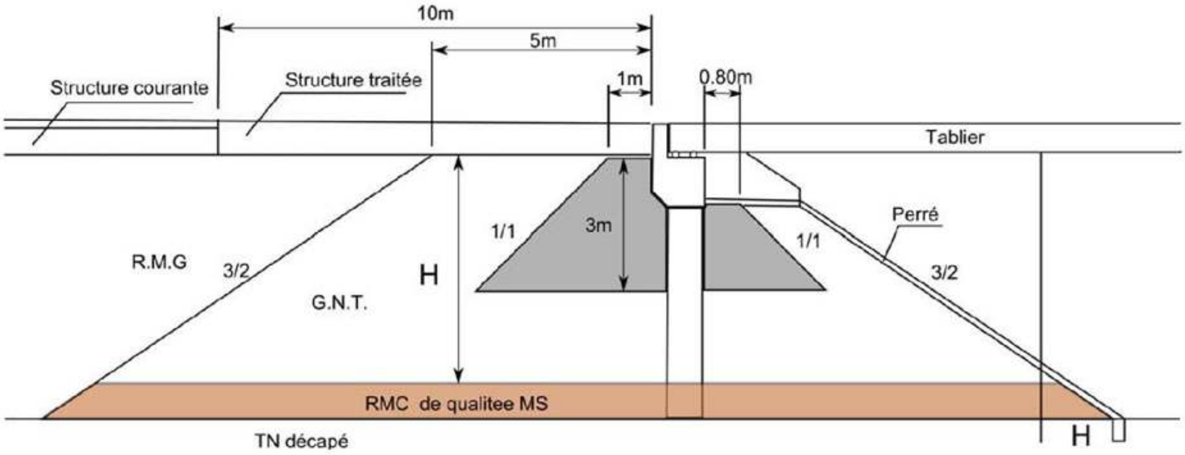

Fig. 4. Configuration designed by the French administration SNCF

Finally, Figure 5 shows the typical solution adopted in the Italian HSL. As in the French case, the height of the treated soil wedge of the technical block is 3 m for heights of the abutment higher than 4 m.

If the height of the abutment is less than 4m, the height of the treated soil wedge will be similar than the height of the abutment.

Geometry of the wedge is similar than that presented by SNCF. The height of non-treated material wedge is similar than the height of the treated material wedge and it has a slope of 2:1, as in the German solution.

The width of the technical block is similar than the height of the abutment but always exceeding 8 m, as depicted in Figure 5.

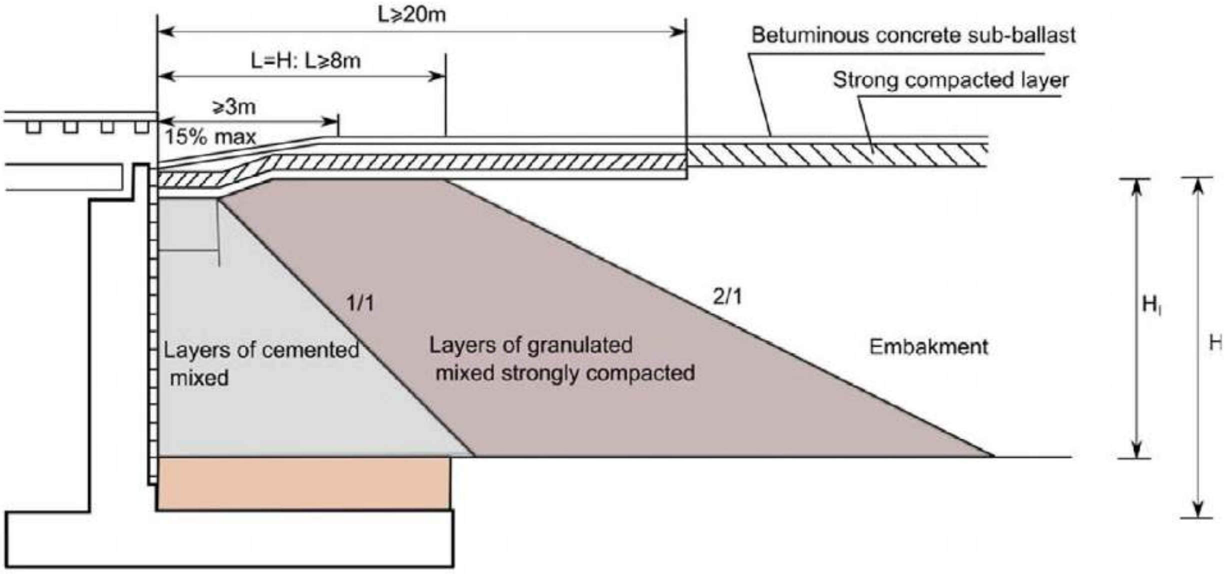

Fig. 5. Configuration designed by the Italian administration FS

Results

As a result of the analysis of international experience on the problems of areas with transient stiffness, it is possible to form an algorithm for identifying such areas on the Ukrainian railways and to develop ways of solving them (Solomka & Ovchinnikov, 2014).

An overview of the options for arrangement of the transition of abutment-embankment on the European railways allows to develop the optimal model of reinforcement of the transitional areas on the high-speed railways of Ukraine (Marochka & Boboshko, 2018), correlating the proposed solutions with taking into account the features of soils, rolling stock and climatic conditions of the country (Petrenko, Tiutkin, Ihnatenko & Kovalchuk, 2018).

As a result of the analysis, an experimental model was developed for further testing in mathematical and experimental models (Figure 6).

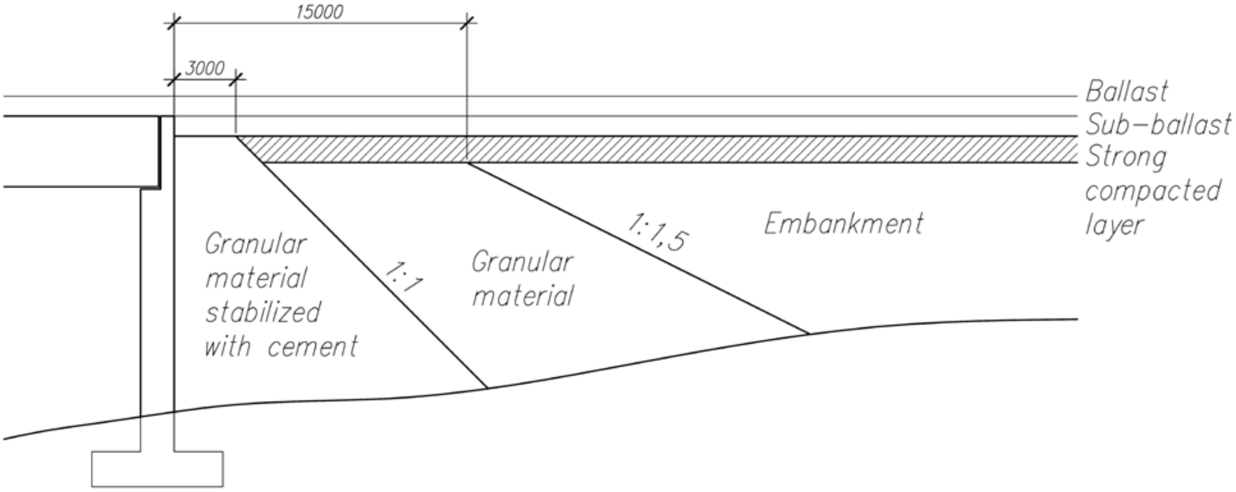

Fig. 6. An experimental model for testing

Originality and practical value

Scientific interest is that, despite the extensive experience of developed countries of the world, the Ukrainian norms still do not have a clear mechanism for identifying and characterizing problems of track geometry in sections with transient stiffness. Thus, studying the experience of more advanced countries in the field helps to consider the problem more clearly and standardize its definition.

If proposed model of reinforcement of transition stiffness areas will be confirmed it allows to reduce the cost of maintaining of the track and to solve the problems of the transitional areas at the stage of bridge construction, that is, before its immediate occurrence.

Conclusions

Based on the research, we can conclude that the problem of transition stiffness is equally relevant for both Ukraine and countries with more developed railway transport structures, and the problem is not new. Despite its high awareness and information base, Ukraine does not have a clear algorithm for solving it.

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АНАЛІЗ ПРОБЛЕМИ ДІЛЯНОК З ПЕРЕХІДНИМ ПОКАЗНИКОМ ЖОРСТКОСТІ У СВІТОВОМУ МОСТОБУДІВНИЦТВІ

Мета. Провести аналіз проблеми ділянок з перехідним показником жорсткості на підходах до мостів на основі досвіду Європейської та Американської сфери мостобудування. З’ясувати основні причини виникнення та методи виявлення дефектів колії в зонах перехідної жорсткості. Запропонувати піддослідну модель улаштування підсилених ділянок з перехідною жорсткістю на основі досвіду розвинених країн Європи. **Методика.** Збір даних щодо причин та характеру виникнення передмостових ям на підходах до мостів на основі досвіду спеціалістів з проектування, будування та експлуатації залізничних та автодорожніх мостів. Аналіз методів улаштування перехідних ділянок на підходах до мостів європейськими країнами. **Результати.** Виконаний аналіз літературних джерел розвинених країн світу щодо проблеми виникнення та методів виявлення передмостових ям на ділянках з перехідним показником жорсткості на підходах до мостів. Зібрані результати щодо шляхів виявлення проблем на ділянках з перехідним показником жорсткості та методів їх вирішення. Запропонована модель для математичних та експериментальних досліджень. **Наукова новизна.** Наукова зацікавленість полягає в тому, що не дивлячись на об’ємний досвід розвинених країн світу, в українських нормах досі немає чітко прописаного механізму виявлення та охарактеризування проблем геометрії колії на ділянках з перехідним показником жорсткості. Отже, вивчення досвіду більш розвинених в даній галузі країн допомагає розглянути проблему більш чітко та стандартизувати її визначення. **Практична значимість.** Запропонована модель підсилення ділянок з перехідним показником жорсткості дозволяє за умови підтвердження її доцільності зменшити витрати на утримання колії та вирішувати проблеми перехідних ділянок на етапі будівництва мосту, тобто до її безпосереднього виникнення.

Ключові слова: міст; перехідна жорсткість; підходи; швидкісний рух; передмостова яма

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АНАЛИЗ ПРОБЛЕМ УЧАСТКОВ С ПЕРЕХОДНЫМ ПОКАЗАТЕЛЕМ ЖЕСТКОСТИ В МИРОВОМ МОСТОСТРОЕНИИ

Цель. Провести анализ проблемы участков с переходным показателем жесткости на подходах к мостам на основе опыта Европейской и Американской сферы мостостроения. Выяснить основные причины возникновения и методы выявления дефектов пути в зонах переходной жесткости. Предложить подопытную модель устройства усиленных участков с переходной жесткостью на основе опыта развитых стран Европы.

Методика. Сбор данных о причинах и характере возникновения ям на подходах к мостам на основе опыта специалистов по проектированию, строительство и эксплуатации железнодорожных и автодорожных мостов. Анализ методов устройства переходных участков на подходах к мостам европейскими странами. **Результаты.** Выполненный анализ литературных источников развитых стран мира по проблеме возникновения и методам выявления ям на участках с переходным показателем жесткости на подходах к мостам. Собраны результаты относительно путей выявления проблем на участках с переходным показателем жесткости и методов их решения. Предложена модель для математических и экспериментальных исследований. **Научная новизна.** Научная заинтересованность заключается в том, что несмотря на объемный опыт развитых стран мира, в украинских нормах до сих пор нет четко прописанного механизма выявления и характеризации проблем геометрии пути на участках с переходным показателем жесткости. Таким образом, изучение опыта более развитых в данной отрасли стран помогает рассмотреть проблему более четко и стандартизировать ее определение. **Практическая значимость.** Предложенная модель усиления участков с переходным показателем жесткости позволяет при условии подтверждения ее целесообразности уменьшить расходы на содержание пути и решать проблемы переходных участков на этапе строительства моста, то есть до их непосредственного возникновения.

Ключевые слова: мост; переходная жесткость; подходы к мостам; скоростное движение; предмостовая яма

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