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МОСТИ ТА ТУНЕЛІ: ТЕОРІЯ, ДОСЛІДЖЕННЯ, ПРАКТИКА

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USING OF FINITE ELEMENT MODELING FOR DETERMINATION OF BUCKLING POSSIBILITY IN LENGTHWISE STIFFENERS OF ORTHOTROPIC PLATE FOR BRIDGE SPANS UNDER OPERATIONAL LOAD

Purpose. The purpose of this research is definition causes of deformation the longitudinal ribs orthotropic plate of the box span structure under the railway. **Methodology.** For solving the problem method was used of finite element modeling. Considered specific metal box span structure set on bridge of Darnytsa crossing in Kiev. The model is loaded in accordance with the actual load, circulating in the area. **Findings.** As a result of simulation received stress-strain state of the beam in the case of loss of stability in one of its ribs. Based on the analysis results showed that the model and variant of its load, closed to the real, do not support the assumption that the deformation of the longitudinal ribs orthotropic plate metal of the box span structure is due to the losses of their stability. **Originality.** For the first time been modeled metal box span structure in accordance with the real load, and Achieved Skill comparison of obtained results with established by the researched. **Practical value.** The results of the research may be used in the furthered exploitation of the metal box of spans of the bridge Darnytsa and refinement of the calculations of this type of structures.

Keywords: the bridge of Darnytsa; loss of stability; longitudinal ribs; orthotropic plate directions; finite element method; modeling

Entry

Combined automobile and railroad Darnytskiy bridge across Dnipro river in Kyiv is being built since 2004. Now both directions of automobile traffic and railway traffic are open.

Fig. 1. General view of bridge's main spans

Bridge has two divided automobile passages – from left bank to right and vice versa – and railroad passage.

Bridge includes watercourse and floodplain parts that have common supports for railway and automobile spans and left bank and right bank ramps with junctions in separated levels.

In spans 1 to 12 of watercourse part there are two-track continuous beams (one with three spans and two with two spans). In spans 12 to 17 continuous combined span is located with two outer beam spans and three arch spans made by scheme 56,5+3×111,6+56,5 м.

On the left-bank overpass of railway ramp in spans 17-1, 1-11 and 17-18 of left and right railways split welded metal beams with rated span of 33,6 meters with ballast track that are manufactured on the «Kurganstalmost» factory according to the standard project № 2210 of design institute «Hydrotransput» (Russia), that was approved and put into operation since 01.06.2002. Project documentation that was executed by subcontractor «PLC "Hyprotransmost"» for named spans, was accepted and included to object's project by general designer of bridge across r.Dnepr in Kiev «Kievdniprotrans».

On the part of left-bank railroad ramp from support № 11 to support № 17 spans of each track made continuous with bearing on metal welded transversal girth rail for providing of spit-level intersection with automobile ramp to upstream passage.

Right-bank ramp is located on industrial territory. Its length equals nearly 1,3 km. For providing of spit-level intersection with downstream automobile passage and old road of quay highway st., railroad tracks were located on metal overpass. Its length reaches 800 m.

Designs of structures (spans and supports) were approved to be similar to those of left-bank ramp.

Two-track railroad overpass of right-bank ramp was built according to project of «Kievdniprotrans» institute and has 24 spans that are overlapped by metal welded integrally transported beams with rated length of 33,6 m.

Spans that are built according to standard project № 2210 have main girders of box-shaped cross-section with metal orthotropic plate of ballast trough.

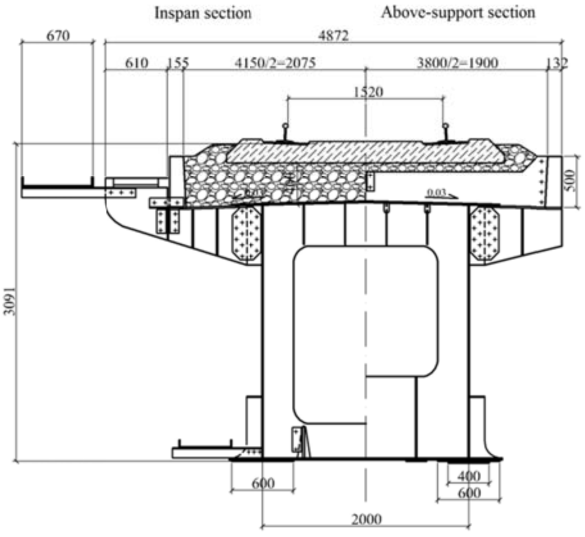

Fig. 2. Cross-section of overpass' beam

Main girder (main block) of span with rated length of 33,6 m according to project № 2210 has U-shaped cross-section and consists of two vertical sides, upper belt that is orthotropic plate and two horizontal plate of lower belt. Orthotropic plate of upper belt has transverse slope of 0,03 from span's axis for outflow of water from ballast trough to drain pipes.

Horizontal plates and vertical ridges are fixed to span's main block by high strength bolt. Main integrally welded box-shaped block of the span can be transported by railway transport.

To overlap the gap between spans, metal plates that match the form of ballast through are placed above the supports. The gap between spans for left and for right track to prevent the spill of ballast is also overlapped by metal plates.

All the spans of right-bank ramp are supported by bearings made according to standard design № 1263 with sector-type movable bearings. Bearings are located on the supports on axes of vertical sides of box-shaped cross-section of main girders. Movable bearings are located in protecting metal case.

Purpose

During bridge survey by Industrial research laboratory of artificial structures (GNDL SS) some transversal curvatures of lower part of lengthwise stiffeners of orthotropic plate in spans that were described earlier of left- and right-bank railroad ramps.

Part of curved stiffeners of their general quantity reaches up to 4 %. Maximum value of curvature amounts 8 mm with allowed curvature value of 3 mm. However the quantity of curvatures of 2…3 mm is much bigger than the quantity of those of bigger values.

According to Laboratory's conclusions analysis of deformation forms evidences that curvatures are not the result of stiffeners' buckling.

This is supported by following circumstances:

- In orthotropic's plate compartments between transversal stiffeners the deformations of lengthwise stiffeners in all cases either are observed not on total length of the stiffeners but on only part of them or have S-like configuration of curvature;
- Generally, within the compartment there is only one deformed lengthwise stiffener;
- Although all the spans of left-bank and right-bank ramps are subjected to equal loading conditions, have the same design and compartment location of orthotropic plate, the deformation of lengthwise stiffeners is not observed on every span

but only in individual compartments of orthotropic plate;

– All the spans are designed for perspective loading C14 with maximum axle loading of 35 tons, which exceeds existing axle loading by the amount of nearly 50 %.

Along with that the welding of lengthwise stiffeners to horizontal plate and transversal stiffeners by two-side welds on the final stage of span's manufacturing in tight conditions can lead to appearance of thermal deformations of relatively flexible stiffeners of orthotropic plate.

There isn't any information or indications that after the welding on the factory the correction of lengthwise stiffeners had taken place.

Besides the analysis of curvature forms, static and dynamic tests of these spans were performed by the Laboratory in order to identifying of actual working conditions of stiffeners under the loading considering their curvatures.

For static tests the locomotive VL80T was used. For ten of its situations on the span stress was measured in two pairs of stiffeners of orthotropic plate. Whereby the pairs of stiffeners were chosen so that theoretical stresses in each pair were equal, but practically one of them was curved and the other one wasn't.

The test data shows the absence of disproportionally big deformations or stresses in stiffeners during spans' loading (fig. 3). This result also shows the absence of local buckling in stiffeners.

Methodology

Despite this, the necessity of buckling possibility of stiffeners of orthotropic plate during spans' operation has arose. For this the decision was made to use the numerical solution of the beam using finite element modeling.

The model's solution consists of following steps:

– Construction of beam's calculation model;

– Finding of such loading distribution model that corresponds best to the real one of this beam;

– For found loading distribution type finding such magnitude that causes the buckling in beam elements.

As a geometric model, rather simple beam made of surface elements was used. Some basic calculations showed that such a model is sufficient enough for our needs.

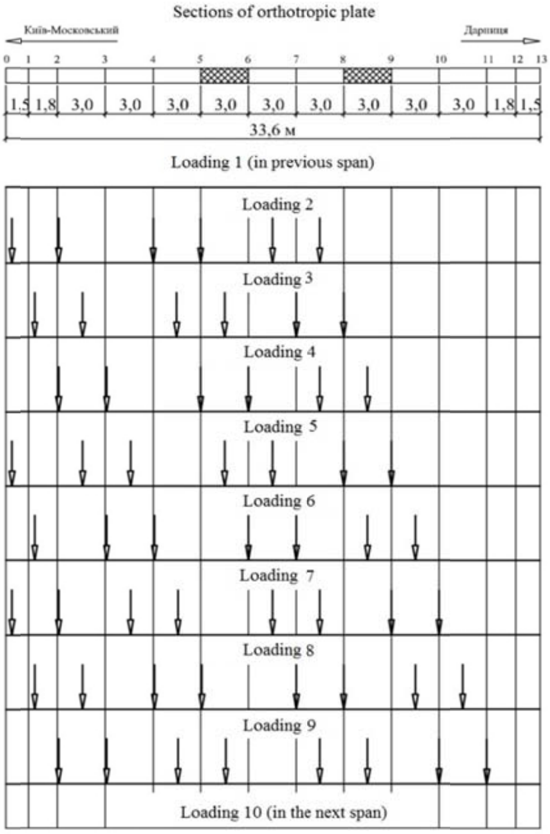

Fig. 3. Span loading scheme for static tests

Another situation occurred with the adequate representation of the load. For finding the load distribution model the results of static tests on spans were used. The results of solution for some version of model were compared to results of static testing. And to equalize them the corrections were made to model loading.

There are some existing models for distributing the wheel's load on several sleepers by the means of the rail. Most used are linear distributions on three and on five sleepers. Calculations showed that these distributions don't represent actual load for the case of these tests. By means of some heuristical and empirical adjustments the loading model that represents the test loads most. It turned out to be hyperbolically shaped with distribution on five sleepers.

After this, using finite-element modeling, buckling problem was calculated. As result we got an adjustment index for conditionally unitary load distribution (that is the load of one locomotive VL80T that was used during static tests), which adjusts the loading to the point where buckling occurs.

Findings

The index, that was found that way amounts 6,76. Thus we can say that with static load with axles positions identical to those of locomotive VL80T, the load per axle should reach 23,75×6,76=160,55 tons to achieve buckling in the beam. In addition to this, modeling showed that buckling will at first occur not in lengthwise stiffener of orthotropic plate, but in the beam's side near the over-support section and in the over-support diaphragm.

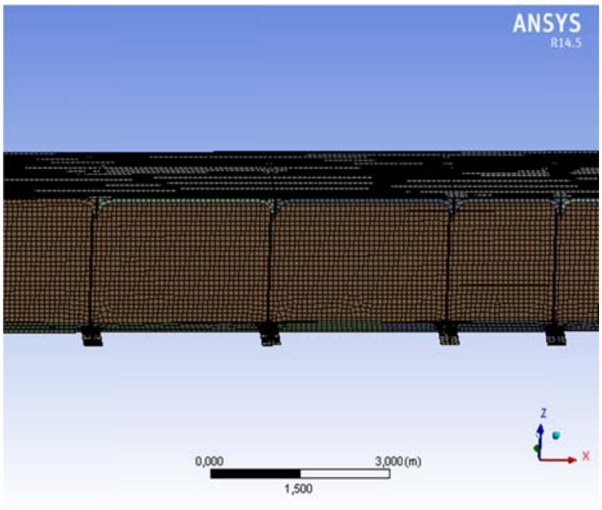

Fig. 4. The fragment of beam model showing finite-element meshing

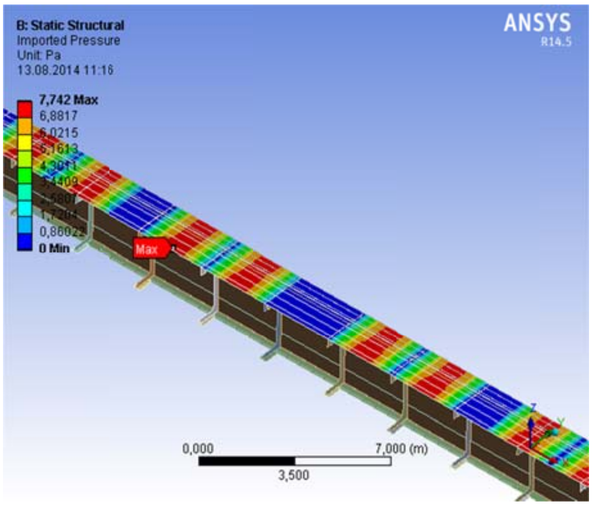

Fig. 5. An example of beam model loading

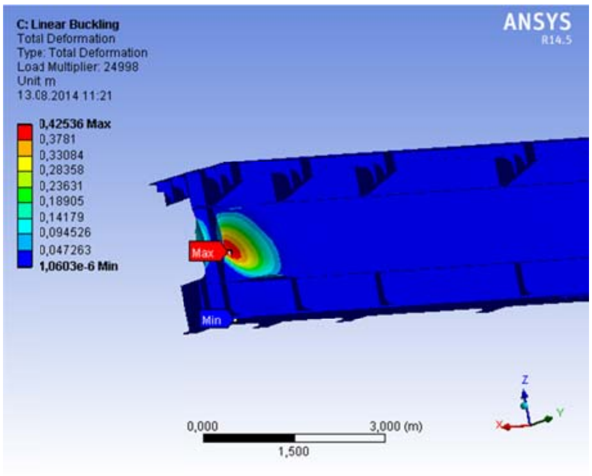

Fig. 6. Deformation contours when modeling critical loads

It's rather easy to calculate now, that equivalent loading for such situation equals 383,48 kN/m, that could correspond to loading class C34, but such loading is not only larger than any of those that are in rotation on the railway but also larger than any loading that is considered as a perspective one.

Although very important remark would be that found loading doesn't consider dynamic part of loads and the real load will be smaller. So considering dynamic factor the loading makes:

$$\frac{383,48}{1+\dfrac{10}{27+33,6}}=329,16\ \text{kN/m}$$

This corresponds to loading class C29, that is still twice as large as perspective rated loading.

Conclusions

Thereby we can guarantee that during spans' operation, if significant violations of operational conditions are absent, the buckling of stiffeners of orthotropic plate cannot occur.

Also this work once again shows that finite element methods are quite useful, convenient and rather easy methods for solving otherwise complex engineering problems.

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ВИКОРИСТАННЯ СКІНЧЕНО-ЕЛЕМЕНТНОГО МОДЕЛЮВАННЯ ДЛЯ ВИЗНАЧЕННЯ МОЖЛИВОСТІ ВТРАТИ СТІЙКОСТІ ПОЗДОВЖНІХ РЕБЕР ОРТОТРОПНОЇ ПЛИТИ В ПРОГОНОВІЙ БУДОВІ ПРИ ЕКСПЛУАТАЦІЙНОМУ НАВАНТАЖЕННІ

Мета. Метою даного дослідження є встановлення причин деформування поздовжніх ребер ортотропної плити коробчастої прогонової будови під залізничним навантаженням. **Методика.** Для розв'язання задачі використовувався метод скінчено-елементного моделювання. Розглянута реальна металева коробчаста прогонова будова встановлена на Дарницькому мостовому переході у м. Києві. Модель навантажена у відповідності до реальних навантажень, що обертаються на даній ділянці. **Результати.** В результаті моделювання отримано напружено-деформований стан балки для випадку втрати стійкості в одному з її ребер. На основі аналізу результатів встановлено, що застосована модель і варіант її завантаження, наближений до дійсного, не підтверджує припущення, що деформація поздовжніх ребер ортотропної плити металевої коробчастої прогонової будови відбулась в результаті втрати їх стійкості. **Наукова новизна.** Вперше виконано моделювання металевої коробчастої прогонової будови у відповідності до дійсних навантажень, та виконано порівняння отриманих результатів із встановленими дослідних шляхом. **Практична значимість.** Результати виконаного дослідження можуть бути застосовані при подальшій експлуатації металевих коробчастих прогонових будов Дарницького мостового переходу та при уточненні розрахунків даного типу конструкцій.

Ключові слова: Дарницький міст; втрата стійкості; поздовжні ребра; ортотропна плита проїзду; метод скінчених елементів; моделювання

МОСТИ ТА ТУНЕЛІ: ТЕОРІЯ, ДОСЛІДЖЕННЯ, ПРАКТИКА

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ИСПОЛЬЗОВАНИЕ КОНЕЧНО-ЭЛЕМЕНТНОГО МОДЕЛИРОВАНИЯ ДЛЯ ОПРЕДЕЛЕНИЯ ВОЗМОЖНОСТИ ПОТЕРИ УСТОЙЧИВОСТИ ПРОДОЛЬНЫХ РЁБЕР ОРТОТРОПНОЙ ПЛИТЫ В ПРОЛЁТНОМ СТРОЕНИИ ПРИ ЭКСПЛУАТАЦИОННЫХ НАГРУЗКАХ

Цель. Целью данного исследования является определение причин деформирования продольных ребер ортотропной плиты коробчатой пролетного строения под железнодорожной нагрузкой. **Методика.** Для решения задачи использовался метод конечно-элементного моделирования. Рассмотрено реальное металлическое коробчатое пролетное строение, установленное на Дарницком мостовом переходе в г. Киеве. Модель нагружена в соответствии с реальными нагрузками, обращающимися на данном участке. **Результаты.** В результате моделирования получено напряженно-деформированное состояние балки для случая потери устойчивости в одном из ее ребер. На основе анализа результатов установлено, что используемая модель и вариант ее нагружения, приближенный к настоящему, не подтверждают предположение, что деформация продольных ребер ортотропной плиты металлической коробчатой пролетного строения произошла в результате потери их устойчивости. **Научная новизна.** Впервые выполнено моделирование металлического коробчатого пролетного строения в соответствии с реальными нагрузками, и выполнено сравнение полученных результатов с установленными исследовательским путем. **Практическая значимость.** Результаты выполненного исследования могут быть применены при дальнейшей эксплуатации металлических коробчатых пролетных строений Дарницкого мостового перехода и при уточнении расчетов данного типа конструкций.

Ключевые слова: Дарницкий мост; потеря устойчивости; продольные ребра; ортотропная плита проезда; метод конечных элементов; моделирование

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