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DYNAMIC AMPLIFICATION FACTOR OF ROAD BRIDGES – ANALYTICAL AND EXPERIMENTAL FINDINGS

Abstract

This paper discusses the problem of theoretical and experimental determination of dynamic factors of road bridges. Various parameters influencing the dynamic behavior of bridges are briefly described and a review of regulations in this field is given. Also, an example of the numerical determination of the dynamic amplification factor on a specific bridge structure using dynamic *time history* analysis in SAP2000 software is presented. Some established methods for the experimental control of the design dynamic amplification on real structures are given, as well as a data and analysis of experimentally obtained results on a series of concrete bridges on the Banja Luka-Doboj highway.

Keywords: dynamic amplification factor, road bridges, time history, experimental analysis

ДИНАМИЧКИ КОЕФИЦИЈЕНТ ДРУМСКИХ МОСТОВА – НУМЕРИЧКА И ЕКСПЕРИМЕНТАЛНА ИСТРАЖИВАЊА

Сажетак

У раду је разматрана проблематика теоријског и експерименталног одређивања динамичког коефицијента мостовских конструкција. Укратко су описани различити параметри који утичу на динамичко понашање мостова и дат је осврт на важеће прописе у овој области. Такође, даје се примјер нумеричког одређивања динамичког коефицијента на конкретној мостовској конструкцији примјеном динамичке *time history* анализе у програму SAP2000. Дат је опис неких устаљених начина експерименталне контроле пројектног динамичког коефицијента на реалним конструкцијама, као и приказ и анализа резултата мјерења на серији бетонских мостова на аутопуту Бања Лука-Добој.

Кључне ријечи: динамички коефицијент, друмски мостови, time history, *експеримeнатлна анализа*

1. INTRODUCTION

As a part of roads, bridges are primarily exposed to impacts caused by vehicle movement. In long term, if not considered, these impacts would not lead directly to the damage or failure of structural elements, but they would cause degradation and reduced durability. So, to design economical and lasting structures of future bridges, but also to economically rehabilitate existing bridges, i.e. to estimate their real carrying capacity, in terms of accepting the current traffic load, it is important to understand the dynamic interaction of the bridge structure and the vehicles crossing the bridge.

The dynamic amplification factor – DAF, can be defined as an increase of the design load due to the effects of the interaction of the bridge and the vehicles, or as the relationship between the observed maximum total effect - U_d and static effect - U_s:

$$DAF=U_d/U_s, \tag{1}$$

The effects observed are mainly displacements and deformations of certain points of the structure. These effects can be easily experimentally determined on a specific structure, using displacement sensors, measuring tapes, or accelerometers, and thus compared with the expected theoretical results.

This paper briefly describes the various factors influencing the dynamic behavior of bridges and also gives a brief review of current domestic regulations which define a dynamic increase of a design load. Furthermore, a numerical example of determining DAF on a simplified finite element bridge model defined in software SAP2000 is presented, where a comparison of the obtained values determined at different vehicle speeds, and a comparison with the values from the regulations is performed. Finally, a description of some established methods for experimental determination of DAF on real structures is given, as well as a review and analysis of experimentally obtained DAFs on a series of reinforced concrete bridges on the Banja Luka - Doboj highway.

2. IMACT PARAMETERS ON DYNAMIC AMPLIFICATION

The dynamic response of one bridge to different vehicles can be quite different, so as the dynamic response of similar bridges to the same vehicle crossing at the same speed. In general, the increase in the response of the structure due to dynamic loading can be induced by the bridge characteristics or by the characteristics of the vehicle crossing the bridge.

When determining the maximum DAF, in some cases, certain combinations of dominant factors are critical, such as a specific bridge structure and corresponding critical speed of vehicle crossing, or a certain heavy vehicles combined with specific road roughness index.

2.1. VEHICLE CHARACTERISTICS WHICH INDUCE AMPLIFICATION EFFECTS

2.1.1. Vehicle speed

The critical speed of a vehicle, i.e. the one at which the greatest increase of the observed relevant effect occurs, is different for different bridge structures. The effect on the structure does not increase with increasing vehicle speed, as might be intuitively expected. In many cases, the dynamic factor is higher at higher vehicle speeds, however, this relation is not linear [1-4].

The value of the critical speed of a typical vehicle for bridge structures which are most often encountered in practice varies a lot. For reinforced concrete bridges with shorter spans (5-15 m), the critical speed, in the range of expected traffic vehicles and speeds in traffic, generally ranges from 40 to 80 km/h, but these values can be even lower [1].

2.1.2. Vehicle weight and damping system

In general, the dynamic amplification on real structures decreases with increasing vehicle weight, as the inertial forces are higher [5].

However, in combination with some other characteristics, the weight can greatly contribute to the increase of DAF. For example, a higher weight at the rough bridge surface will give a larger DAF. Also, if vehicle axles are without damping, it will produce high DAFs, while softer axles, give lower factors and good load distribution. [6-9]

2.1.3. Number and distance between vehicles

The Monte Carlo method, used in statistics to determine the probability of different outcomes in the process, is most often used to define the probable load on bridges. Using this method and traffic data for a certain section, it is possible to determine the critical, most unfavorable cases that can occur during the operation of the specific bridge. Dynamic analysis can be performed for several critical cases, however, the greatest critical static load case may not give the greatest dynamic effects.

In the case of short to medium span bridges (20-30 m), the critical traffic load usually consists of two heavy trucks meeting in the middle of the bridge span, however, each bridge structure is unique, and a critical case cannot be easily predicted in terms of number vehicles, axle weights, and axle spacing. [5]

2.2. IMPACTS OF STRUCTURAL CHARACTERISTICS ON AMPLIFICATION EFFECTS

2.2.1. Bridge frequency impact

As emphasized in the relevant regulations, when determining DAF, the span of the bridge has a large impact, which is reflected in the value of the natural frequency. Also, the weight of the bridge affects its frequency, the heavier the bridge, the lower the dynamic amplification. Besides inertia, a larger cross-sectional area of the load-bearing elements of the structure reduces the dynamic impact, since the stiffness of the structure is increased, which gives higher natural frequencies.

The DAF is significantly influenced by the ratio of vehicle speed and bridge frequency [6,9-10].

2.2.2. Bridge damping impact

In general, the damping value significantly affects the intensity of the dynamic factor. As the damping level in the structure decreases, the dynamic factor increases.

As the structure is assumed to work in the elastic region, damping can be modelled as *internal viscous damping*, which occurs due to the viscosity of the material, and which is easy to consider in the numerical models.

2.2.3. Bridge surface roughness impact

The impact of this parameter largely depends on the span of the bridge. In general rougher road surfaces produce larger dynamic effects during the crossing of vehicles. The roughness of the bridge surface affects the dynamic amplification to the greatest extent on shorter bridges, i.e. those with higher stiffness, having short natural oscillation periods. [9-12]

3. DYNAMIC AMPLIFICATION FACTOR IN APPLICABLE DOMESTIC REGULATIONS

Many current regulations, in general, do not require dynamic analysis when designing the bridge structure. Instead, dynamic effects caused by vehicle-bridge interaction are accounted for by multiplying the static live load by DAF.

DAF for a specific bridge structure is conditioned by many parameters, and in most regulations, many important characteristics of bridges and vehicles are neglected, so the calculations in this way are quite conservative. [13,14]

In this geographic region, in the field of analysis of the impact on bridges, EN 1991-2 (2003): *Eurocode 1: Actions on structures – Part 2: Traffic load on bridges* and the *Rulebook on technical norms for determining the load on bridges* are in use.

According to *Eurocode 1: Actions on structures – Part 2*, dynamic factors are already included in different types of design load for road bridges. Vehicle models already have a "built-in" dynamic factor. These "built-in" amplifications are determined by the range and shape of the influence line, which depends on the lanes of the vehicle model [15,16].

Figure 1 shows the dynamic amplification factor as given in the *Eurocode 1* as a function of bridge length and the number of lanes.

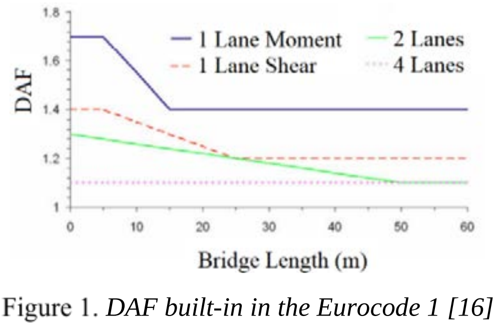

Figure 1. *DAF built-in in the Eurocode 1 [16]*

According to the *Rulebook on technical norms for determining the load on bridges*, all loads that are entered into the calculation of structural parts of the bridge, except for the end and middle pillars, must be multiplied with the dynamic factor K_d. The dynamic factor for road bridges is a function of the span length of the bridge, and it is defined by the expression:

$$K_d=1{,}4-0{,}008L\geq 1 \ , \qquad (2)$$

where L (m) is the relevant span length. In the case of continuous beams, L is the bridge span in which the typical vehicle is located. When transmitting a force in two or more directions, L is the smallest span. [17]

According to the formula above, in the case of the relevant span length greater than or equal to 50 m, factor K_d has a value of 1, neglecting the dynamic effects due to traffic load, which is not in the line with the experimental and theoretical considerations.

In summary, according to the *Eurocode*, the dynamic factor is a function of the span length and shape of the influence line, while according to the *Rulebook on technical standards for determining the load on bridges*, the dynamic factor is only determined by the span of the load-bearing structure.

The values calculated this way are conservative, but mostly on the safety side, although they do not take into account many significant parameters of vehicle and structure.

Parameters such as surface roughness, damping, structure geometry, vehicle speed, and other vehicle characteristics can hardly be generalized and included in regulations.

4. NUMERICAL DETERMINATION OF THE DYNAMIC AMPLIFICATION FACTOR

Analytically, the dynamic equation, i.e. the functional dependence of the velocity and the values of the dynamic factor for a simple beam is given in [2,18].

In the section below, a description of the numerical calculation of the dynamic factor, by performing dynamic analysis in the program SAP2000, is presented.

4.1. NUMERICAL MODEL DATA

In the numerical example presented herein, the analysis of the impact of certain bridge and vehicle parameters was performed on the FE model of a concrete bridge.

The bridge is continuous with three spans, with ranges of 16 m, 20 m, and 16 m, respectively. The main structure consists of 10 prestressed T-girders with a total height of 2,4 m, and an axial distance of 6 m. The concrete slab cast over girders is 25 cm thick. The pillars are of reinforced concrete. This bridge structure type is characteristic on the Banja Luka - Doboj highway.

Several significant simplifications have been made in the bridge and vehicle models, to clearly see the impact of variable parameters on dynamic amplification. The influences of all variable parameters were observed on a two-dimensional model of the bridge, without considering torsion, and the load was applied in a form of a concentrated force. Vehicle vibration and surface roughness were ignored.

The value of the dynamic factor depending on the speed of load and the load mass was observed on three different bridge models, which differ only in terms of the height of supports, i.e. longitudinal stiffness of the structure, since points 3 and 7 have restricted vertical movement (Figure 2).

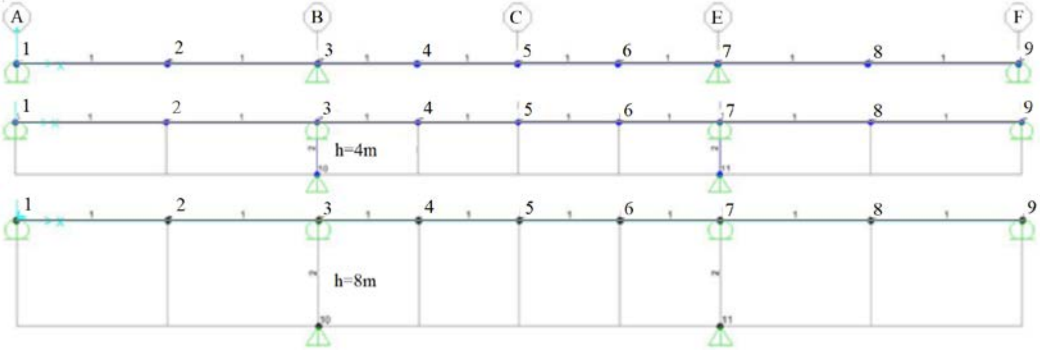

Figure 2. *Bridge models: Model 1 - rigid supports, Model 2 - 4 m high supports, Model 3 - 8 m high supports*

In the software SAP2000, the method of *Linear Time History Analysis* was performed and the load was applied as moving load. As the model is simple, in *Time History Analysis, the Direct Numerical Integration* method, and the *Newmark* method with the coefficient $\beta = 1/4$ were used. Depending on the speed, the time steps are in range from 0.001 to 0.0005 s.

In [2], this method of analysis was compared with the numerical solution, where the deflection of the simple beam was determined by the partial differential equation of motion and the moving load was defined by the *Dirac function*. The agreement of the obtained results was presented in Figure 3.

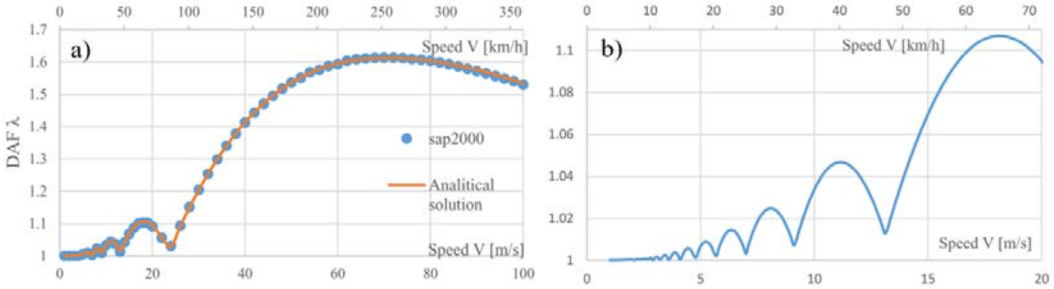

Figure 3. *DAF as a function of load speed movement - comparison between numerical solution and analysis in SAP2000 for simple beam: a) time period 0-100s, b) time period 0-20s. [2]*

4.2. RESULTS OF THE NUMERICAL ANALYSIS

The analysis showed that at very low speeds, dynamic factor is close to 1, as the dynamic influences are small, and with increasing speeds, its value oscillates, as it depends on the excited oscillation modes.

Figure 4 gives a visual overview of the point deflection in the middle of the bridge span, obtained via the procedure above described, for model 1, with rigid supports, and with variation in mass and velocity of moving point load.

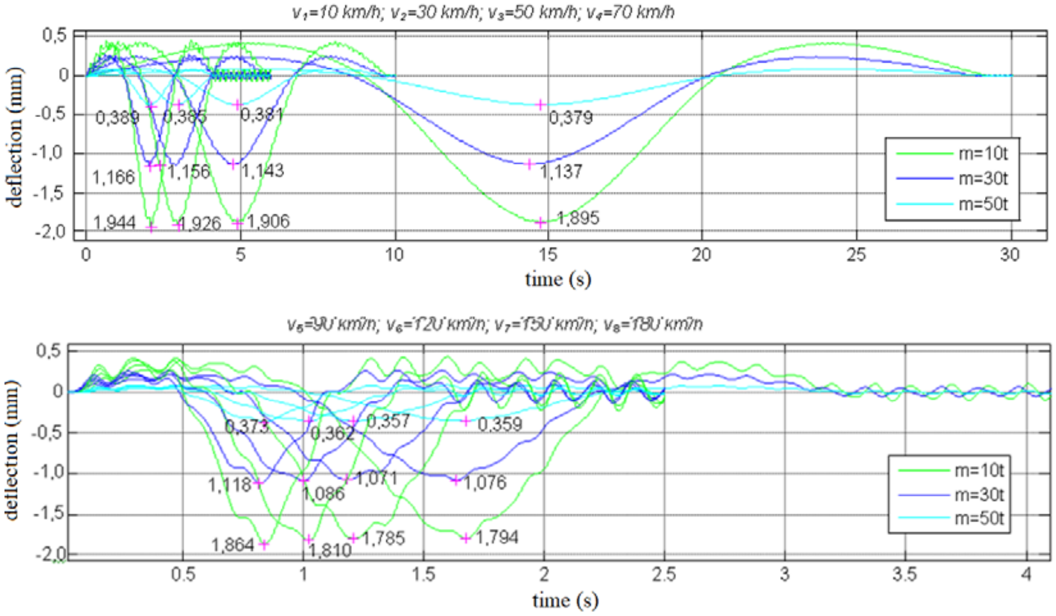

Figure 4. *Deflections in the middle of the span at different time intervals for model 1, speeds of 10-180 km/h*

Even at close speeds, for example, 160 km/h and 180 km/h, DAF values show significant differences, and they also differ for different models, as presented in Figure 5. The results are shown for unreal vehicle speeds, over 200 km/h, to emphasize the speed impact.

The calculation was repeated for 3 mass values of the point load – 10t, 30t and 50t. It was concluded that, for this case of the two-dimensional model, with even pavement, the load mass does not affect the values of dynamic deflections.

Stated results, obtained with variations of only three parameters – load mass, load speed, and structure longitudinal stiffness (which depends on the height of the columns), indicate problems in the theoretical determination of the dynamic factor in the design stage when performing dynamic analysis, as small differences in the model and vehicle speed can greatly affect the DAF values.

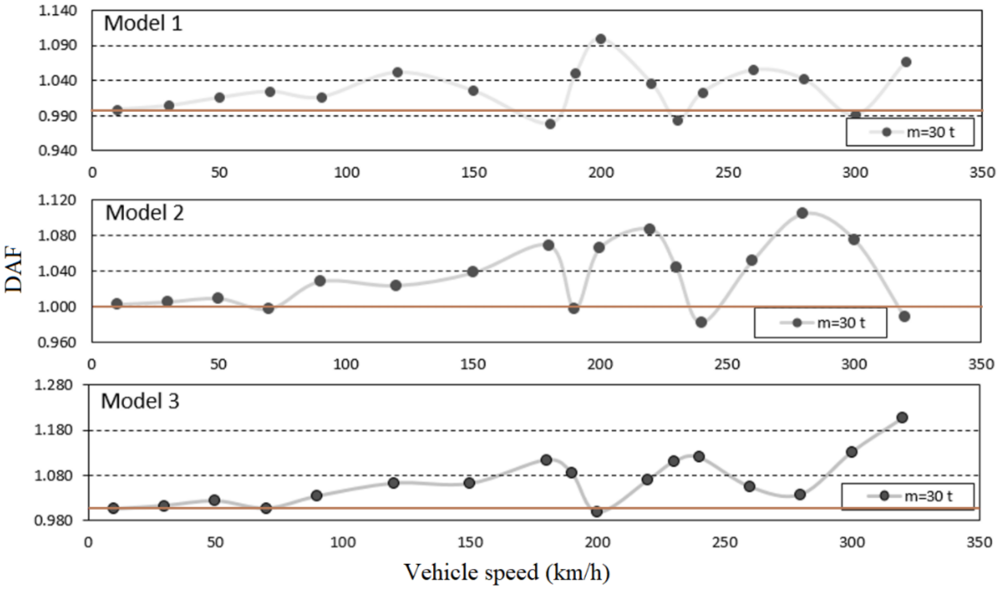

Figure 5. *DAF values in relation to vehicle speed*

Using the expression (2) defined by the rulebook [17], which does not take into account longitudinal stiffness, or vehicle speed, obtained dynamic factor for the largest span is 1,24. This value is higher than all the values obtained in all three models, at real vehicle speeds. It can be concluded that taking the design value, over the numerical value, in this case, is on the safe side.

If some other parameters were considered in the dynamic analysis, such as surface roughness, this might not be the case.

5. EXPERIMENTAL DETERMINATION OF THE DYNAMIC AMPLIFICATION FACTOR

After the construction or rehabilitation of bridges, it is necessary to perform static and dynamic load testing, to compare with the design data.

The most common parameters that describe the dynamic behavior of a structure are the dynamic factor, natural frequency, and damping. All these parameters can be found experimentally from the structure response diagrams, i.e. by measuring certain quantities on the structure over time.

5.1. METHODS FOR THE DYNAMIC AMPLIFICATION FACTOR EXPERIMENTAL DETERMINATION

Experimentally, the dynamic factor can be obtained in several ways [19-22]. The most reliable way of determining DAF value for a specific bridge is a *full-scale dynamic-testing* under *controlled traffic*.

Depending on the method for measuring the maximum value of the static response, the following expressions can be used [19]:

$$DAF=R_{dyn}/R_{sta} \tag{3}$$

$$DAF=R_{dyn}/R^{dyn}_{sta} \tag{4}$$

$$DAF=R_{dyn}/R_{fil,sta} \tag{5}$$

$$DAF=R_{dyn}/R^{dyn}_{fil,sta} \tag{6}$$

Where following labels are used:

- R_{dyn} – maximum dynamic response,
- R_{sta} – maximum static response obtained by placing the vehicle in the appropriate position, or maximum quasi-static response obtained by driving the vehicle at low speed and recording the maximum value,
- R^{dyn}_{sta} – quasi-static response obtained by driving the load at low speed and recording the value at the corresponding time and location of maximum dynamic response,
- $R_{fil,sta}$ – maximum static response obtained by filtering the measured dynamic response with a low-pass filter to eliminate dynamic signal components (when measuring displacement or

strain in time with digital instruments, dynamic time records contain both static and dynamic component),

- $R^{dyn}_{fil,sta}$ – static response obtained by filtering the measured dynamic response with a low-pass filter to eliminate dynamic signal components, which is determined for the point in time when the maximum dynamic response is obtained.

When the filtered response is equal to the quasi-static response, equation (4) corresponds to equation (6), and also equation (3) to equation (5).

The graphical explanation for possible values of static response is provided in Figure 6.

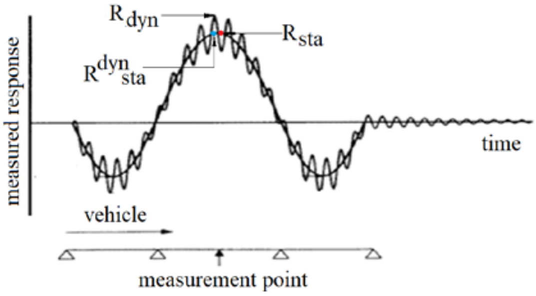

Figure 6. *Possible values of static response*

When using R_{sta} - the static response obtained in the test load by placing the vehicle in the appropriate position or quasi-static response obtained when a vehicle is passing the bridge at low speed, or $R^{dyn}_{fil,sta}$ - the maximum response obtained by filtering the measured dynamic response, smaller values of DAF are obtained. That also means that equations (3) and (5) give smaller DAF, compared to (4) and (6).

So, in the case when a static component is not measured separately but extracted from dynamic time records, recorded displacement or strain amplitude time histories contain both static and dynamic components of the bridge response. Extracting the static component from displacement time histories is performed by filtering techniques, using a low-pass filter which eliminates the dynamic component. The low-pass filter blocks all frequencies lower than the set limit frequency. The eigenfrequency of the bridge is the basis for selecting the cut-off frequency required to perform dynamic record filtering. Therefore, it is preferable to first measure the bridge eigenfrequencies, performing ambient measurements. [20,23]

On the technical side, when determining the dynamic factor, it is important to place the instruments in the appropriate cross-section zone. The middle of the transverse span is recommended, in order to measure effects in the zone of direct impact, and thus avoid an increase of the dynamic amplification, which can occur if measurements are made outside the zone of direct impacts, such as on pedestrian consoles. [19]

During the dynamic testing, the vehicle can cross the flat surface of the bridge at various speeds or it can cross over the installed *obstacle*, i.e. obstacles on the road. Also, the dynamic impact can be measured after *sudden braking*, which is a more common way in practice today, compared to using the obstacles.

Typically, for medium span bridges, the impact is measured when one vehicle passes the bridge, when two vehicles pass one after the other, or when they meet each other.

Mechanical deflection meters, inductive linear displacement sensors or optical devices can be used to measure deflection, and appropriate strain gauges can be used to measure strains.

5.2. EXPERIMENTAL DETERMINATION OF DYNAMIC AMPLIFICATION FACTOR ACCORDING TO THE JUS U.M1.046 STANDARD

According to the standard JUS U.M1.046 - *Testing of bridges with test loads*, it is required to measure the deflection during the load passing over the bridge and to record the speed of passing. It is not required to place an obstacle on the pavement, or to perform sudden braking.

The dynamic behavior of the bridge is considered satisfactory if the measured free vibrations are within the theoretical values, if the dynamic factor is within the limits defined in the main design, and if the vibrations do not create a feeling of discomfort for the users [24].

6. DYNAMIC AMPLIFICATION FACTOR DETERMINATION ON A SERIES OF REINFORCED CONCRETE BRIDGES

During the years 2016 and 2018, the *Institute for Materials and Structures Testing* of the Republic of Srpska performed a series of load tests on the new concrete bridges and overpasses on the Banja Luka-Doboj highway. The load tests were performed following the JUS U.M1.046 standard, which, considering dynamic tests, requires the measurement of vertical deflection in the middle of the span during the load passing over the bridge and observation of possible deformations and review of the general condition of the structure after dynamic testing.

According to the established practice until then, for all dynamic measurements, a 5 cm thick wooden plank was placed on the structure, representing a possible obstacle or unevenness on the pavement.

6.1. BRIDGE STRUCTURES DATA

The tested bridge structures are classified into 4 basic types:

- **Type 1** - structures located on the main road, framed, with one, 9 m long span. Bridge slabs are reinforced concrete 70-80 cm thick, integrated with supporting columns.
- As the bridge structures were separate for different highway directions, measurements were made on a total of 4 structures of 2 bridges.
- **Type 2** - structures located on the main road, framed, with 3 do 5 spans. Bridge slabs are reinforced concrete 70-80 cm thick, integrated with supporting columns.
- As the structures were separate for different highway directions, measurements were made on a total of 11 structures, always in a first span with 12 m length.
- **Type 3** - structures located on the main road, continual, consisting of 10 prefabricated prestressed concrete T-beams, transversal beams at supports, and pavement slab, as a monolithic layer, which is concreted on-site over the upper flanges of the prefabricated T beams. This type of bridge has spans of 15+3x20+15 m.
- Measurements were made on a total of 4 structures, always in the second span, with the length of 20 m.
- **Type 4** – structures located off the main road, continual, with 4 to 6 spans, consisting of prefabricated prestressed concrete T-beams, transversal beams at supports, and pavement slab, as a monolithic layer. Depending on the category of the road passing highway, this type consists of 5-8 T-beams.
- Measurements were performed on medium spans of 20 m length on 13 structures and of 24 m length on 3 structures.

Typical bridges and corresponding cross-sections on the main road (type 2 and 3) and on the side roads (type 4), are shown in Figure 7.

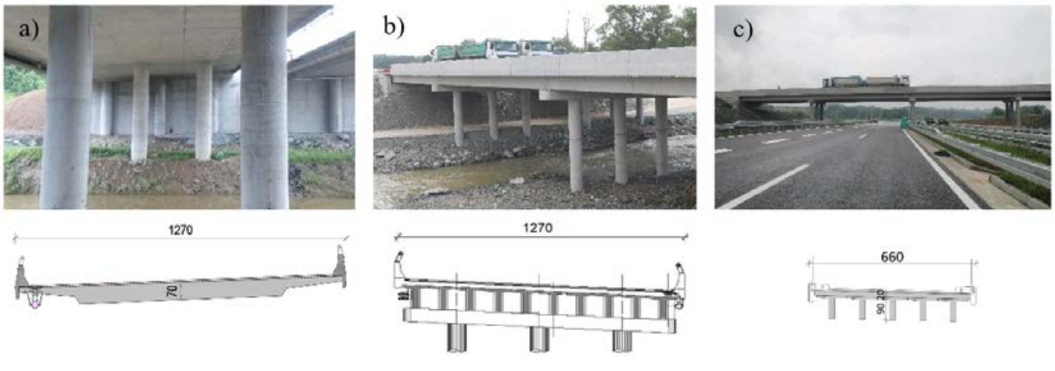

Figure 7. *Typical bridges and corresponding cross-sections: a) bridges on the main road - type 2, b) side roads bridges - type 3, c) side roads bridges - type 4.*

6.2. MEASURING EQUIPMENT

Devices for measuring dynamic displacements are placed at characteristic locations, i.e. at the locations of maximum deflections, determined by the control static calculation.

Measurements were performed by *HBM half-bridge inductive displacement sensors*, with an accuracy of 0,14% and with measuring range of 40 mm. Some of the measured dynamic factors obtained with inductive displacement sensors were compared with the values obtained by measuring local deformations using *„Hottinger“ strain gauges of type LY41 50/120*, however, these values were not included in the analysis. All devices were connected to the *HBM MX840A eight-channel universal measuring system* and *HBM CATMAN –EASY data acquisition software*. The sampling frequency when measuring dynamic response was 600 Hz.

6.3. EXPERIMENTAL SETUP

Depending on the load test program, trucks with a total weight of 32 to 38 t were used. The disposition of vehicles used is shown in Figure 8.

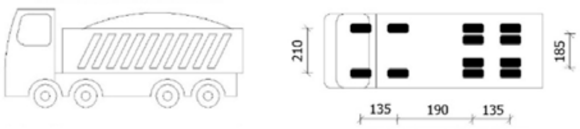

Figure 8. *Test load vehicle disposition*

To determine dynamic factor, the vehicles were moving at speeds in the range of 40-60 km/h, over a wooden plank with a height of 5 cm, placed at the location of the predicted maximum deflection, also where the measurements were also performed. After conducting the dynamic test and removing the plank, vehicles drove on the same path with a crawling speed of 5-10 km/h.

Deflection in the vertical direction is recorded in a form of a time history. According to Figure 9, at the same location, using the same instrument, the time history signal is recorded for dynamic and maximum quasi-static deflection. Therefore, the DAF is computed through the expression (3).

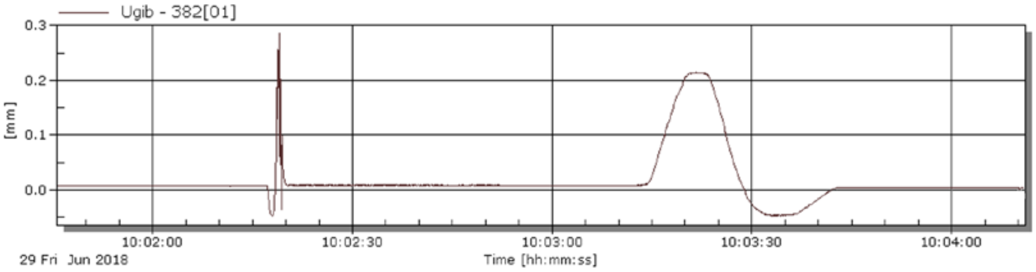

Figure 9. *Time history signal example for dynamic and quasi-static deflection*

Two instruments were placed within the characteristic cross-section on most structures, thus two measurements were recorded during one test.

Except for dynamic deflections, other relevant parameters which were measured: the speed of the loading vehicles, the temperature of the structure, the ambient air temperature, and weight of the vehicles.

6.4. MEASURING RESULTS AND ANALYSIS

The results of maximum dynamic and quasi static displacements are calculated as the mean value of the obtained measurements, in case of two measurements in one cross section.

Also, as stated, the results were controlled through the values obtained with the strain gauges, if they existed in the appropriate sections. Dynamic factors determined by strain measurements are not presented in this paper, as some studies have shown that factors determined in this way have lower values than those obtained by deflection [19], so it was decided that the measurements used to determine DAF are uniform. Only data obtained through inductive displacement sensors were used.

Some characteristic dynamic deflection records are shown in Figure 10.

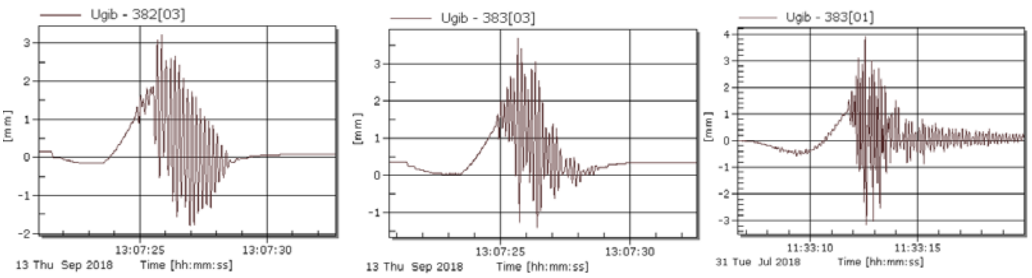

Figure 10. *Examples of obtained time history signal for dynamic deflection*

The design dynamic factor in the project documentation is calculated through expression (2). The measured dynamic factors show different values, in the range of values from close to 1, to over 2, Figure 11. As can be seen in Figures 11 and 12, the results obtained show a certain dispersion.

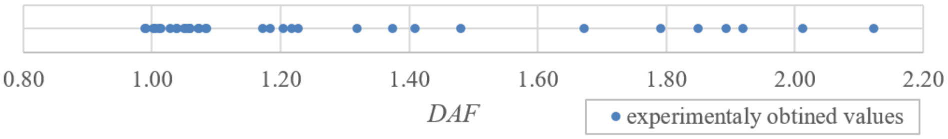

Figure 11. *Experimentally obtained values of DAF for all types of structures*

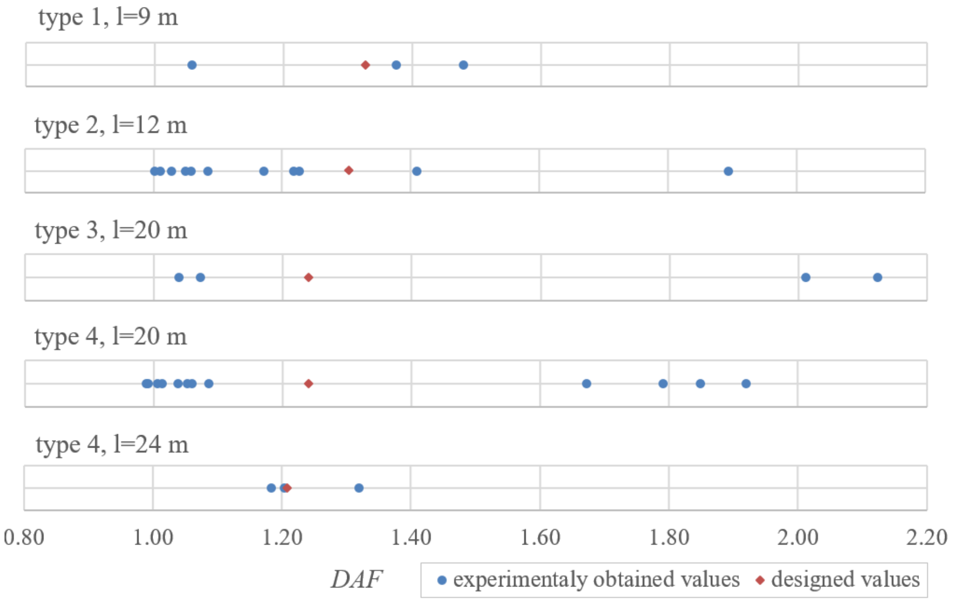

Figure 12. *Experimentally obtained values of DAF classified by types of structure*

Most of the results obtained experimentally are lower than the design values, however, several results significantly exceed these limits.

Previous experimental research [19,22] have shown that the impact of road surface irregularities on the measured DAF is large, and that, in general, when testing with an obstacle on the road significantly higher values of dynamic factors are obtained. These research also suggest that further analyses are needed on this subject. Experimental tests have shown high DAF values (over 2) in the case of passing vehicles at low speeds (20 km/h) over the plank [10,19]. When the tests are performed by the load passing over the plank, it is not possible to correlate with the numerical values, nor predict behavior under such conditions. Regardless, the plank has been often used in practice, since in this way dynamic behavior is emphasized, and possible unevenness or obstacles on the road are simulated.

Generally, for smaller bridge spans, higher dynamic factors are obtained, which agrees with the expressions defined by the standards, as well as the experimental results [19]. In the research presented herein, there are not many results for small-span bridges (type 1), however, it can be concluded that higher dynamic factors were obtained for bridges with a span of 12 m (type 2), compared to those with a span of 20 m (type 3 and 4).

Some experiments with plank returned dynamic factors with value of 1 and slightly lower than 1 [10], although this is not supported by theoretical considerations. This was the case here for the small number of results, for structure type 4, where values less than 1 were obtained, although the signal sampling frequency was 600 Hz. Similar values were obtained using strain gauges.

For structure type 3, there are 4 test results, determined on 2 bridges of equal span and pavement width. Although these bridge structures are nominally the same, the results show significant deviations, even the tests were performed under the nominally same conditions - the only parameter that varied through the measurements was the speed of the vehicle crossing the obstacle - 40 and 60 km/h, respectively. This occurrence can be explained by differences considering bridge structure, which could be the result of the execution or differences in bearings or supports.

As the weight of the vehicles variated between 32 and 38 t, depending on the bridge structure, and the speed was 40-60 km/h for either weight, conclusions on weight and speed influence cannot be made.

7. CONCLUSIONS

Determination of dynamic amplification factor, either numerically or experimentally, is a rather complex problem. As there are a large number of parameters that affect its value, many are neglected in the regulations, since they are difficult to generalize and include in general equations. The factors defined by the regulations are mainly a function of a small number of parameters (span, influence line), and therefore they are quite conservative.

In a simple dynamic numerical analysis in the SAP2000 software package, it was shown that small variation in the model parameters, in terms of bridge structure longitudinal and bending stiffness, and the speed of the moving load, greatly affects the values of DAF. The value obtained by the expression defined by the rulebook [17], is higher than all the values obtained in numerical analysis, at real speeds, for all three models. It can be concluded that choosing the design value, over the numerical value, in this case, is on the safe side. If some other parameters were considered in the dynamic analysis, such as surface roughness, this might not be the case.

As in the numerical analysis, so in the experimental determination of DAF, there are many parameters to consider, from calibration, position and method of setting measuring instruments, to placing the vehicles in the exact position when measuring both static and dynamic response. All these parameters have great impact on results, thus it is important to perform very precise measurements.

The results obtained by experimental research on a series of concrete bridges on the Banja Luka – Doboj highway show a great dispersion. All results were obtained using a plank. In general, experimental analysis using plank gives larger values of measured DAF. This method cannot show a correlation with the numerical model, in order to make conclusions on the structure response, and has been abandoned in today's practice. To emphasize the dynamic effects, sudden braking is more used nowadays. Even with plank, generally, for smaller bridge spans, higher dynamic factors are obtained, which agrees with the expressions defined by the standards, as well as with the theoretical and experimental findings.

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