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GEOMETRY DETERMINATION OF HYBRID SYSTEMS

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ABSTRACT: In this paper a hybrid system created by parallel coupling and form active element is presented. These hybrid systems, with different spans, height and mechanical characteristics of individual elements were analyzed by FEA models. This paper is an attempt to draw attention to the problems and issues that accompany these systems with an aim to find the ideal geometry.

Numerical analysis results of the models with different section active element (BEAM) cross-sections, form active element (TENSION) on different levels and positions of the vertical compression elements were observed. The results obtained were used to determine the interdependence between these elements and the influence of vertical element position on efficiency and overall system stability. Special emphasis is given to vertical compression elements which had in the previous research proven to be the major factor affecting the geometry of hybrid systems.

KEYWORDS: Hybrid system, Outside prestressed girder, Lightweight structure, Glue laminated girder

1 INTRODUCTION

Two static systems with different force transmission capabilities can be connected together in a new system-hybrid static system. Obviously, it cannot be determined with accuracy who performed the first hybrid system and when. The very idea of hybrid systems probably did not exist as such, but it has been designed by sheer coincidence and made into what we today consider as hybrid systems.
Hybrid system can not be seen as a set of two or more separate systems within which one has a greater role than the other. The presupposition is that base systems transfer load acting upon them by joint action. In other words, in order to transfer the load, two or more systems depend on each other and they are of the same importance for the transmission of load.

Systems of this type are unique and they can not be classified into any known group of static systems.
Those systems can be described as follows:

- they do not have a unique way to transfer force;
- they do not develop normal response to the force;
- usual characteristics of structural system cannot be applied to them.

Hybrid systems are not specific only according to mechanical transfer of force or characteristic shape. They are also specific regarding the behaviour of the merging systems and their response to load.

During the analysis of hybrid systems as the project solution, the following phenomena have been noticed: a reciprocal decrease in the critical stress, exceeding capacity more than double the capacity of individual components in the system and an increase in stiffness; all observed in relation to the material consumption between hybrid system and some primary replacement system. When designing hybrid systems it is of huge importance to create unity between two different systems in terms of mechanical stability, resistance and find the method for the joint action of two different systems.

In the design of hybrid systems, it is of great importance to achieve unity between two different systems regarding mechanical stability and resistance as well as to find ways for joint actions of those two systems.

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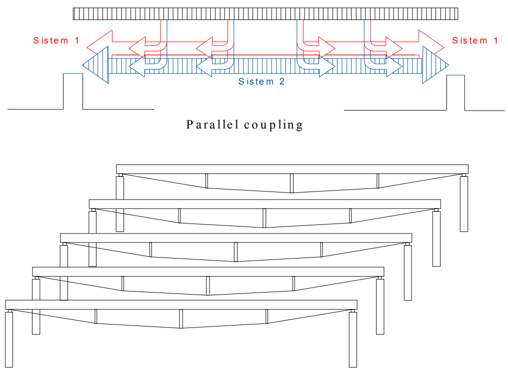


***Figure 1:** Force transfer in hybrid systems*

The process of dimensioning hybrid systems refers to its decomposition into simpler elements and their dimensioning. Major problem refers to determining inner forces and deformations. As it most commonly regards statically indeterminate systems, programme packages are used for that purpose.

After inner forces have been determined, dimensioning follows according to valid norms. During this step it is most simple to decompose the hybrid system into simpler parts and dimension each according to their respective standards. Emphasis is put on the standards required by certain material since in the hybrid systems synergy between two or more materials occurs.

The loss of stability of hybrid systems may be categorised into global (shapes characteristic for this kind of structures) and local stability (elements that constitute a hybrid system).

It is clear that the system that is dependent upon the girder elements (in roof plane) may have problems with lateral buckling and thus, the stability will be dependent upon lateral supports. The introduction of horizontal stabilization and secondary bearing structures for local stability of girder elements has an important impact on global stability of the system.

It remains to deal with the problem of the tension element, i.e. the tie that connects vertical compression elements and form active element. That kind of loss (as shown in Figure 2) shows horizontal decline at the tie that connects vertical compression elements and the tension element.

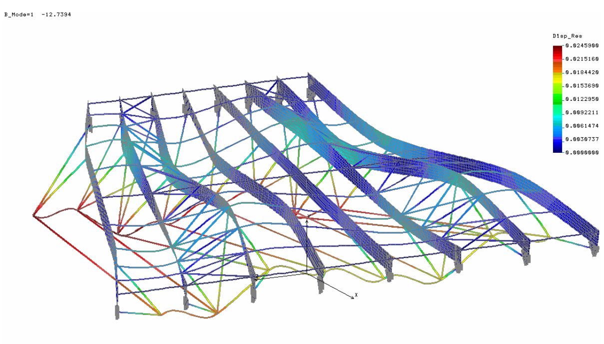


***Figure 2.** The loss of stability of the hybrid system - buckling coefficient 12,74*

It is a unique phenomenon to cause the loss of stability resulting from the upward buckling. The latter results from the actions of prestressed forces that aim at diminishing deformations caused by dead load.

There are two different situations that may cause the loss of stability:
- exceeding the planned prestress force during installation;
- occurrence of the raising action of the wind in the design life.

Taking into account all that has been said, theoretically, the structure may be in unstable equilibrium as a result of prestressed forces that will annul dead load completely so that even minimal action in the opposite direction to the gravity force may cause the structure to collapse. In other words, one part of deformation resulting from the dead load is allowed being the system reserve.

***Figure 3.** The installation of the roof hybrid construction of swimming pool in Sesvetski Kraljevac*

One of the most common questions during the design is how to determine the ideal or appropriate geometry for the hybrid system made by parallel coupling of two different basic systems (Figure 1 and 3). In this paper we have tried to determine the interdependence between: the height of a hybrid system, stiffness of the beam element and position of vertical compression elements.

2 APPROACH TO THE GEOMETRY OF HYBRID SYSTEMS

2.1 THE DESCRIPTION OF THE APPROACH TO THE GEOMETRY OF HYBRID SYSTEMS

In practice, hybrid systems have proven to be one of the simplest engineering solutions in cases of huge spans. Their drawback is a lack of knowledge about their mechanical properties and a lack of understanding regarding specific problems of such systems. In this article, we have attempted to clarify the steps in the design of hybrid systems.

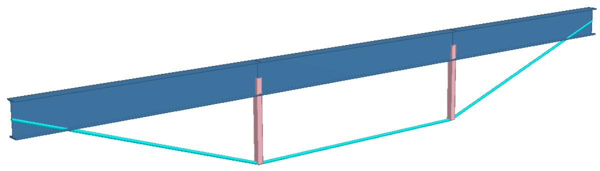


__Figure 4.__ Axonometric view of numerical model
The selection of the girder may be outlined as follows:

2.1.1 Section active element

If the hybrid system that is observed possesses relatively low height when compared to its span, in order to ensure increased compression force (which may be achieved by the reaction of form active element) higher resistance of element to compressive force should be provided. On the other hand, if the system has greater spans, i.e. bending moments and lower compression force (which may be achieved by the greater height of the hybrid system when compared to the span), greater resistance of cross section to bending moment should be provided.
What is the perfect ratio between the section modulus and the area of the cross section, it is still unknown. What remains is to use iterative method in order to achieve that ideal ratio.

2.1.2 The shape and material of the section active element

It is also important to decide what to use: glue laminated wood or steel H and I profiles. The choice depends directly upon the section active element but also on the architectural requirements.

2.1.3 The overall height of the bearing element

Changing the height of the system has a relevant impact on the forces in the form active element, i.e. on the compression force in the section active element. Most often, the height of the system is limited by the height of the usable space beneath the structure and therefore it determines the space which is at disposal for the bearing structure.
If hybrid system is analysed in detail, depending on its height it is noticed that the height of these systems results in an increase in their stability and vice versa: lowering the height results in non-reliability and sensitivity to stability loss due to great axial forces.

2.1.4 The span between the vertical compression elements

The position of the vertical compression elements that are to be attached to the section active element has a relevant impact on the moment graph of the section active element and the graph of axial forces in the section active element and form active element. The importance of the position of the vertical compression elements may be explained by the great interdependence among all the elements of the hybrid system as well as by the overall functioning of this system.

2.1.5 Prestressed force in the tension element

Prestressed force has a great impact on the efficacy of the hybrid systems. Numerical models that have been taken into account in this article have not considered the prestressed force as its usage may have caused more problems.
The application of the prestressed force is common as it annuls the deformations resulting from the constant load. Consequently, the prestressed force diminishes deformations and overall height of the system may be thus diminished. Therefore, it may be concluded that the prestressed force should not be applied on the systems with extremely low height and it should have such a value that annuls deformations caused by dead load.

2.2 A BRIEF OVERVIEW OF THE METHODOLOGY USED IN ANALYSIS OF HYBRID SYSTEMS

The research was conducted using software **Staad.Pro 2007** and **COSMOS/M**. Design issues in behaviour of hybrid systems have been addressed using different models. The problems that our research has addressed have been considered in the previous paragraph. The analyses performed ranged between 13.0 m to 20m.

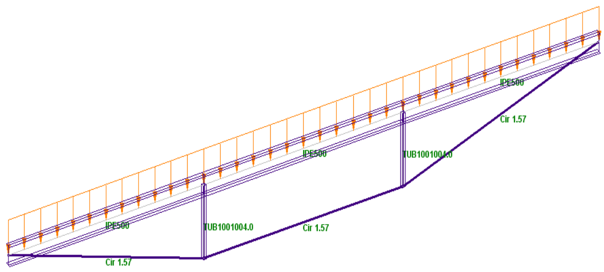


Figure 5. *Load and cross section of numerical models*

As we have already pointed out, these systems are not subject to superposition rule. Therefore, one load has been set containing two basic loads (self weight and live load) and is also factorized in accordance with the EC1 regulations.

Entire research was conducted with the aim to determine the position of vertical elements that could lead to the greatest design ratio of the beam element. The first model was made with constant height - 10% of its span and with the constant cross section of beam and tension element. It has been our attempt to determine the relationship between design ratio of beam element and position of vertical compression element using the mentioned model. To achieve that, continuous loading on the girder element was introduced as a variable.

Drawback of the previous models was non including the diameter of tension element in research. To be more precise tension element is in all models and load cases designed with the same diameter, which is not the correct assumption. The following research was conducted on the same models as in the first case. However, there was the difference in the diameter of tension element in relation to the axial force. Using this iterative selection of tension element diameter in relation to the load is an attempt to determine the dependence and impact of the tension element on the position of vertical compression elements.

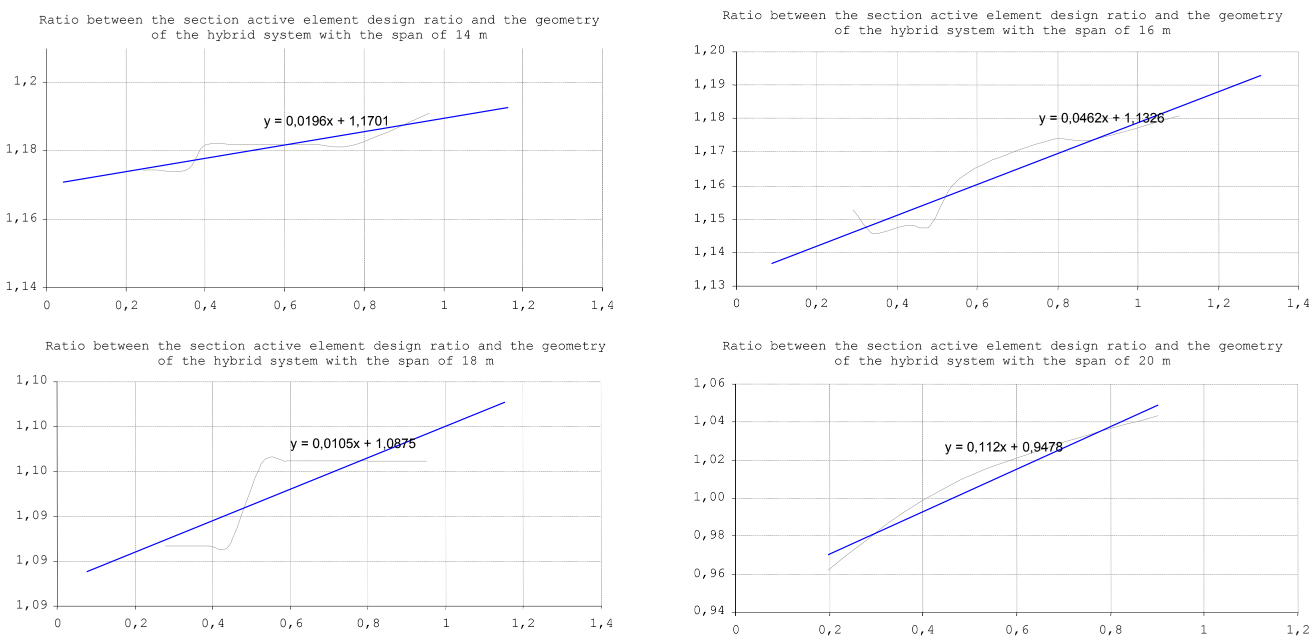
Change of beam element resistance and the influence on the geometry of a hybrid system is observed on a series of 14.0 m spans hybrid systems numerical models. The study was conducted with three section modulus of beam element, compared to the previous in which the section modulus of this element was constant. As in previous models, the goal was to find ideal position of vertical elements and studying their position in relation to the design ratio of beam element.

In the introductory section, it was mentioned that the height of a hybrid system is often limited with usable height under load-bearing structures. However, the influence of the height on the geometry is not negligible and therefore it was included in the latest models. The two numerical models were conducted including the span of 14.0 m, respectively 10% and 18% of the total span of the system. The aim of the latter was to confirm that the height itself acts upon the position of vertical compression elements.

3 RESULTS OF ANALISYS

For the analysis some of the results were considered as shown in the charts. These charts show the relationship between the geometry of hybrid systems (the ratio of edge and central span) and the design ration of the beam element.

The first numerical models were meant for the analysis of the impact of beam design ratio on the bearing capacity and geometry of the system. Assuming that the change in geometry of the system is linear, we have analysed their impact in case of the following spans: 14m, 16m, 18m and 20m. The first graph shows two types of results; grey lines connect the results obtained by a series of numerical models, whereas blue lines show approximation of the results. Fluctuations that are visible on the grey line can be explained as the inability to find an ideal location with sufficient accuracy, since the obtained results were approximated using the third decimal. Due to slight declines, the results obtained were approximated using the straight line function as shown in the graphs.
If we consider linear approximation of the results, it can be seen that the results do not show major changes in the geometry of the hybrid system depending on the beam element design ration.

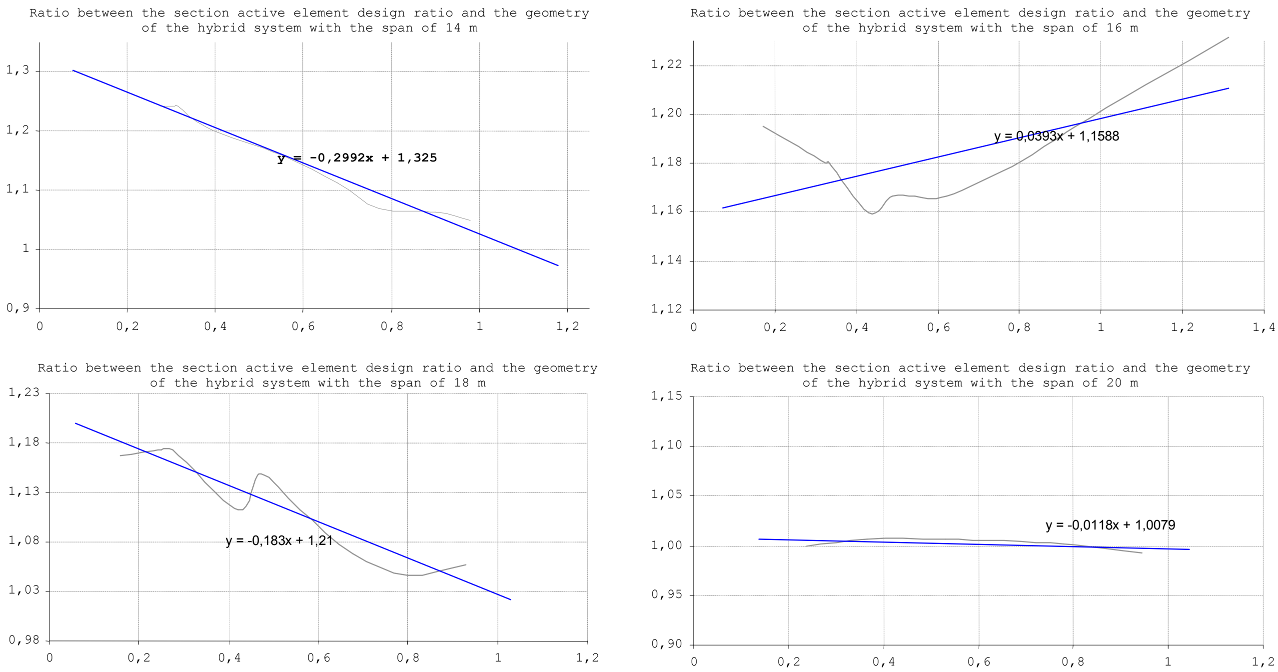


***Graph 1:** Results obtained by numerical models with a constant diameter of form active element*

From these results it may be concluded that the vertical compression element position is not the same for all hybrid systems spans. In practice, it is a tendency to ensure structure elements design ratio between 80% and 100%. Under this assumption, if we consider the results obtained within that range, the required geometry changes between: 1.2 for the span of 12m; and falls linearly to 1.06 for the span of 20 m. With respect to the linearity of results it may be concluded that the ratio between the edge and central span equals 1.0.

Graph 2 shows the results of the second type of numerical models in which the tension element was introduced as a variable. The results show greater influence of tension element to the geometry and major changes compared to the previous results.

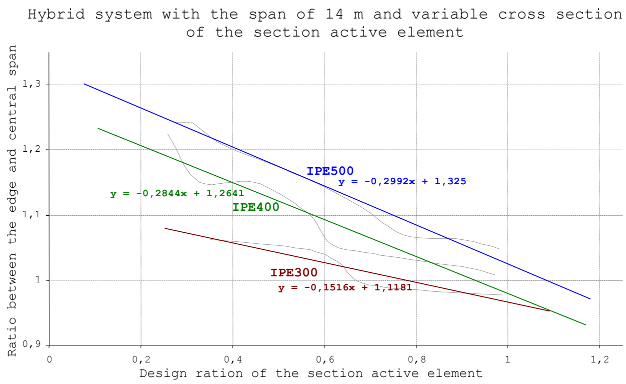
The results show differences compared to the results obtained with first models and for same problems results are in the larger range then we expect. From these results very little can be concluded, except that the geometry depends not only on the design ratio of individual elements and their relation to each other but also on the section modulus of hybrid system and his main span. This conclusion may be confirmed by analysing the results obtained for the span of 16 m. Linearization of results show that the ideal curve increases with the design ratio of the section active element, which is the in opposition with our previous results.



Graph 2: *Results obtained by numerical models with a constant diameter of form active element*

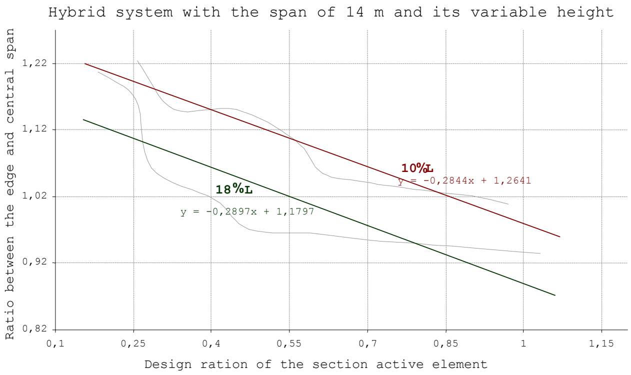
Under the previous assumption we may put the following question. What happens with the geometry if only cross section of beam element is being changed? An answer to this question may be offered by using the following numerical models created for the 14 m span hybrid system in which the following beam element figures are taken IPE 500, 400, 300. In this case the tension element is variable and is kept at full design ratio in accordance with the loads that have appeared. Graph 3 shows the results obtained by the described numerical models using the variable beam element cross section.

The results show a larger trend for larger cross-section girder and it ideal geometry is within the range of 1.3 to 1.0. The numerical model with a smaller cross-section applied to girder requires a smaller ratio regarding the spans in order to achieve the ideal geometry and the same approximation trend is not as steep as the previous one.



Graph 3: *Display results of numerical models with variable section active element*

The last research was conducted on numerical models of 14 m span, but in this case the height of the hybrid system served as the variable. As it is evident from the Graph 4. the results obtained for these two cases of numerical models are parallel.



***Graph 4**: Display results of numerical models with variable section active element*

Numerical models of hybrid systems with smaller height require greater ratio between edge and central span than the systems with greater height. Explanation for this can be found in the rigidity of the system, i.e. at smaller height most of the load is carried by the section active element, whereas the form active element acts upon the vertical compression element as a very soft spring support.

Contrary to these assertion, models of hybrid system with greater height of which the form active element is lower, has a capacity to take on greater efficient load while the stiffness of the spring support is increased.

4 CONCLUSION

Research in hybrid systems is rather scarce and this paper is an attempt to draw attention to that problem. With the experience and information from the worksite, it is concluded that there is a lack of knowledge regarding such systems in terms of their stability and force transfer. Insufficient data in professional literature and rare use of these systems is probably the reason why in the assembling but also in design there are failures.

In the first part we have attempted to give a brief overview of specific problems associated to the hybrid systems. Stability is explained through a description of local and overall losses and engineering solutions for their prevention.

In the second chapter an overview is given regarding the elements, their impact and importance of the capacity of the entire hybrid system and the mutual dependence of individual elements. It has been our aim to determine the geometry that would provide its maximum utilization in order to determine mutual dependence between individual elements involved. From the results obtained, we can claim with great certainty that the geometry depends on the relative resistance of the cross-sectional section active element and the span of the hybrid system. Consequently, the ratio between the edge and central span increases with the stiffness of the section active element.

Tension element position and its diameter are very important factors in determining the ideal geometry. Research has shown that an increase in one of these parameters results in the ratio between edge and central span which is equal to 1.0. The charts show that the hybrid systems at low height and at ratio between the edge and central span of 1.2 result in an ideal geometry. With an increase in height the ratio drops to 1.0, and even to 0.95 in cases of rather low resistance of the section active element and rather high hybrid system. The results display rather big interdependence of the required geometry of the hybrid system in relation to the complex cross section (made up of the section active element and the tension element) and the span of the hybrid system.

Further research is to offer more precise results and broaden our knowledge regarding the impact of the prestressed force on the geometry of the system.

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