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ДВА РАЗЛИЧНИ АНАЛИТИЧКИ ПРИСТАПИ ЗА МОСТ СО КОСИ ЗАТЕГИ

РЕЗИМЕ

При проектирање на мостови со коси затеги, генерално има два пристапи како принципи на анализа на нелинеарниот систем. Првиот пристап е за аналитички модел на целосна конструкција, со главен акцент на генералната крутост на системот и добивање на крајнта форма од нелинеарната анализа. Вториот пристап е за аналитички модел што во себе ги опфаќа различните фази на изведба на челичната конструкција, до комплетирање на целокупниот носив систем. Во овој труд, анализиран е пешачки мост со коси затеги према горенаведените аналитички пристапи. Главната цел е да се добијат компаративни резултати од нелинеарната анализа, и да се истакнат разликите во вредностите и распределбата на внатрешните сили на конструктивните елементи на мостот.

Клучни зборови: мост со коси затеги, нелинеарно однесување, фази на монтажа.

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CABLE STAYED BRIDGE ANALYSIS WITH TWO DIFFERENT APPROACHES

SUMMARY

When designing cable stayed bridge, as a principle for structural analysis, generally there are two approaches for the analytical research. Namely, the first approach is for analytical model as a whole structure, where the main consideration is for the rigidity of the structure and for obtaining the final form of the structure from the nonlinear analysis. The second is for analytical model that takes into consideration the phases of the construction of the steel structure, until the completion. In this paper, a cable stayed pedestrian bridge is analysed according to the two approaches mentioned above. The purpose of this research is to compare results obtained from nonlinear analysis, to address the difference in the values and the redistribution of the internal forces of the elements of the bridge.

Keywords: cable stayed bridge, nonlinear cable behaviour, stage construction.

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1. INTRODUCTION

For the analytical purposes, a cable stayed pedestrian bridge is considered. The bridge is composed of two trusses as a beam with four spans of 29 m and total length of 116 m, supported through cables on single pylon. The pylon is leaned so the weight contributes to the positive behaviour of the structure, as a natural behaviour of rope pulling stance, as shown on Fig. 1. The first, second and the last support is rigid, where the middle two supports are the cables of the bridge. The height of each truss is 1.45 m, with distance between of 4.0 m. The composite pedestrian deck rests on secondary beams connecting the two trusses. The deck is composed as composite structure from adequate steel sheeting, reinforcement and concrete, supported by the steel beams. The composite structure is enabled with usage of (through deck welded) headed studs for connecting the deck with the beams.

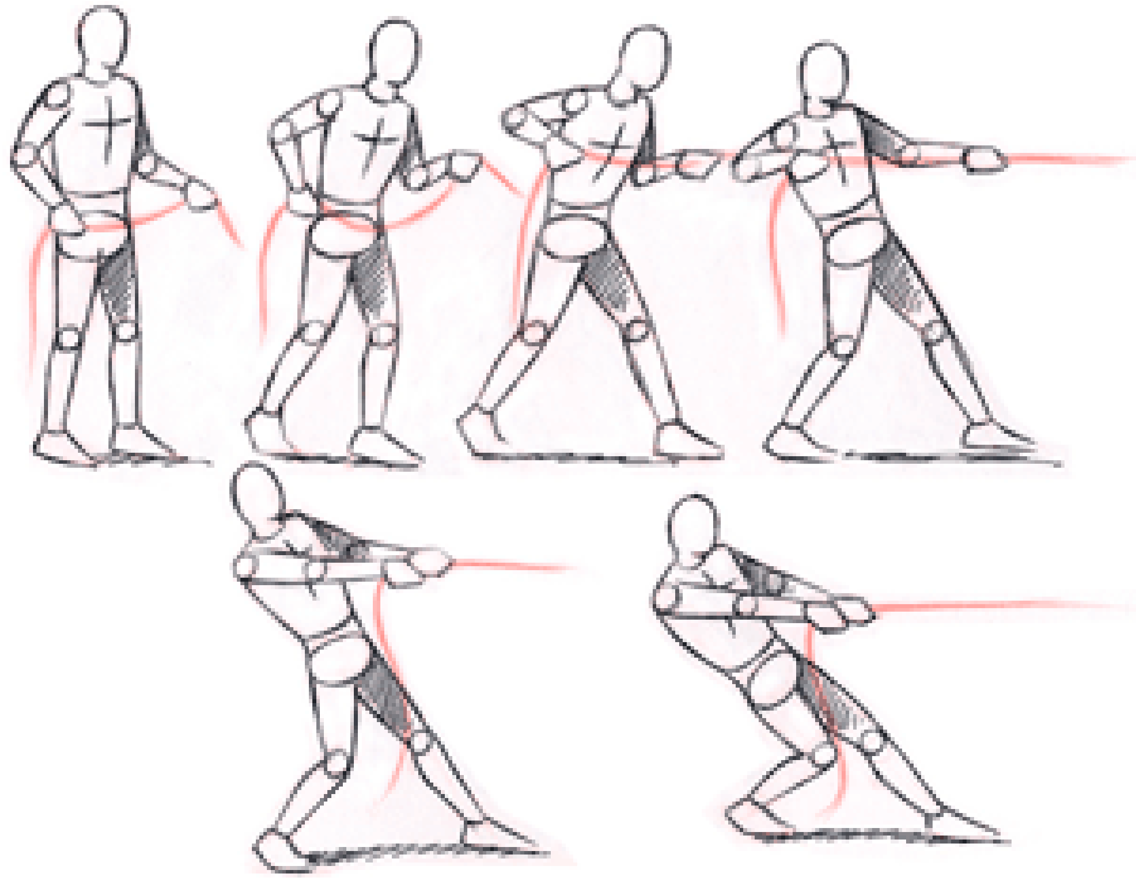

Fig. 1. Natural pulling stance

The loads acting on the bridge are simulated through application of dead loads in different stages of execution and live load, simulating pedestrians. Their influence on the bridge behaviour is analysed through modelling with two different analytical nonlinear approaches. The first one does not take into consideration the different phases of the execution of the structure, since it considers the whole structure, where the main problem is the displacement of the nodes of key elements, and maintaining the final form that meets the requirements for the serviceability limit state. The second approach analyses the staged construction with different analytical model of all the different stages of execution, taking into consideration the most favourable form of the system. Thus, the main goal is obtaining the results from the different models and comparing their differences which are commented in detail.

The cable stayed pedestrian bridge is fully designed with all details, support elements and joints so that they can meet the requirements of the structure [1]. The structural model is 3D created, where workshop drawings, CNC files and other technical documentation can be obtained, as displayed in Fig. 2.

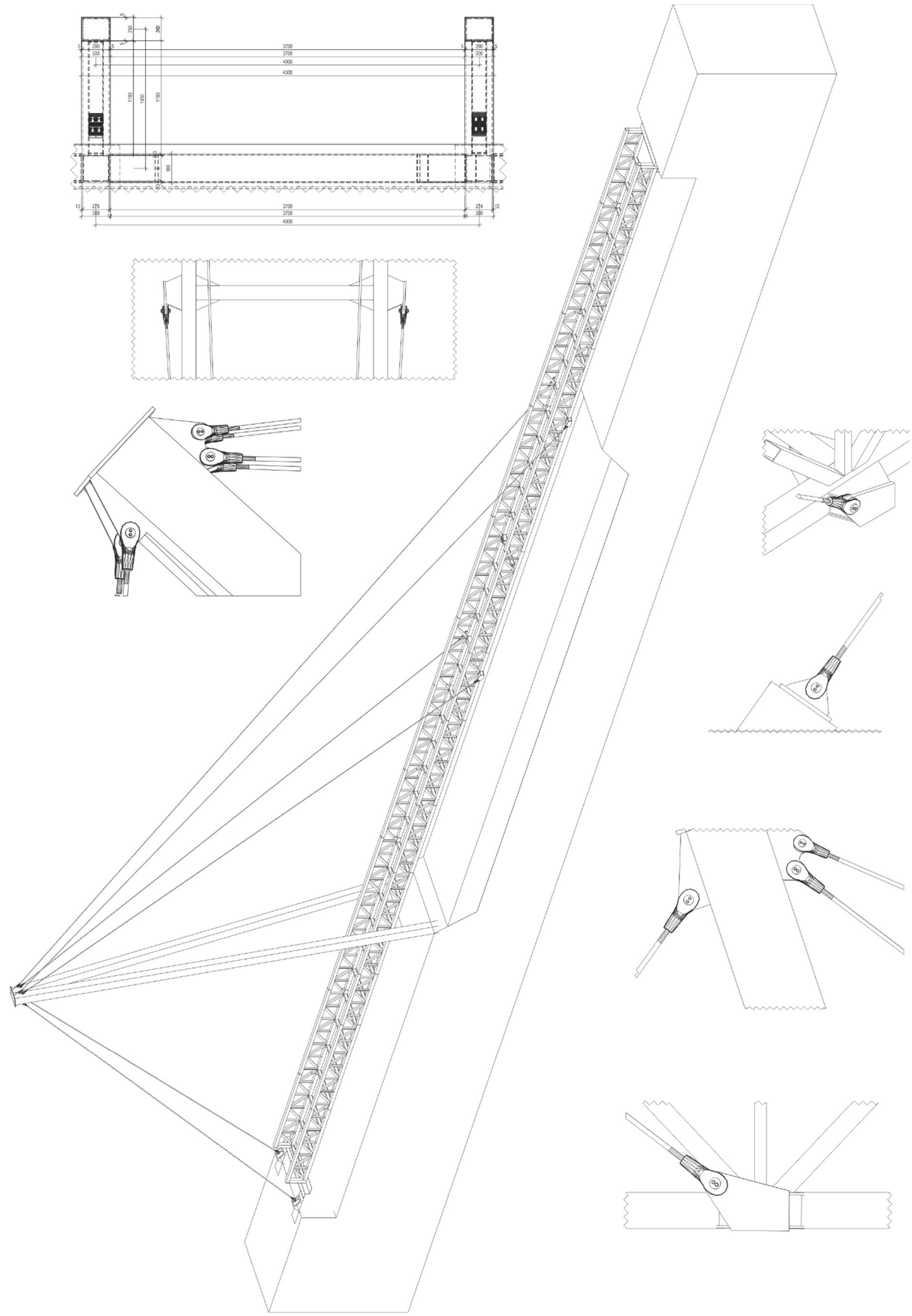

Fig. 2. 3D display of the cable stayed pedestrian bridge

2. METHOD 1, NONLINEAR ANALYSIS OF FULL STRUCTURE

The model for this analytical approach is final result from other models analysed by a decomposition method for obtaining the final form of the structural system. The decomposition method firstly started with simplified model of the main truss beam, obtaining the reactions at the supports where the cables meet the truss. The second model is with support simulating the pylon, connected by cables on the truss beam. This simplified model simulated the nonlinear behaviour of the structure, which leaded to the completion of the final model for the nonlinear analysis of the whole structure. For this model, two separate loading cases were made, dead and live loads (pedestrians). The cable is defined as cable - tension element, analysed with nonlinear behaviour of the structure, with previously defined restrains of the joints at the top of the pylon, and the joints where the cables meet the truss, where the displacement of these joint must tend to zero for dead loads. The full displacement and the internal forces are obtained through nonlinear analysis with both load cases of the structural system (Figure 3).

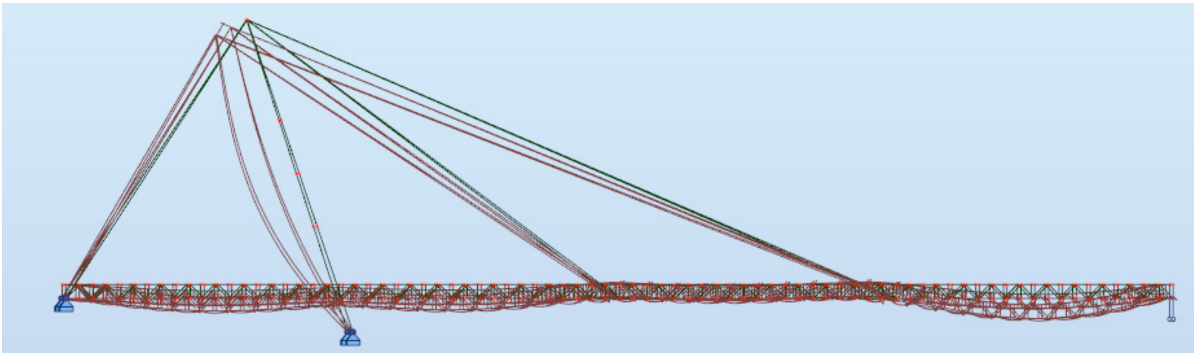

Fig. 3. Deformed shape for both dead and live loads

The main comparison points for the model are the displacements of the joints at the top of the pylon, the joints at the contact cable truss, the maximum displacement at the last span, the maximum axial force in the top and bottom chord, maximum axial force in the cables and the maximum stresses in the pylon, analysed for the most unfavourable load combination.

In Table 1 are given the displacements δs, forces N_{Ed} and stresses σ_{Ed} obtained in method 1, for the main points of interest and comparison between the two methods.

Title	δ_s [mm]	**Title**	N_{Ed}, σ_{Ed} [kN, N/mm2]
Top of pylon	22.2	Top chord	-1912.76
Third support – cable	38.7	Bottom chord	-2606.60
Fourth support - cable	42.8	Cable 1	+1543.99
Max. displacement	72.2	Cable 2	+1067.36
		Cable 3	+2181.42
		Stress in pylon	175.44

Table 1. Displacements and forces

3. METHOD 2, NONLINEAR STAGED CONSTRUCTION

For this analytical approach, a new model in another software was made, with specified loading cases in every stage, according to the real erection plan of the steel structure for the pedestrian bridge. This can be achieved in nonlinear analysis case so called staged construction, where elements or part of the construction can be added or removed, in accordance with the erection plan, with loading in every different stage of the execution.

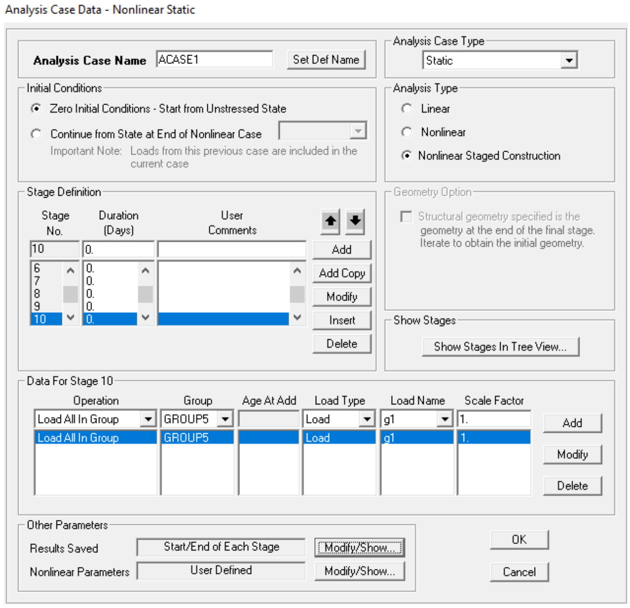

Fig. 4. Defining loads at different stages

In this model the same rules apply, where the displacements of the same joints are constrained. For example, the displacement at the top of the pylon, and the joints where the cable and the truss beam meets, must be tending to zero for the last stage of the execution of the structure loaded with dead load. This can be achieved by pre-stressing the cables by shortening to the analysed final length at the end of each stage. With these rules, the final form of the nonlinear behaviour of the structure is obtained, and the final length of the cables is defined. The maximum displacement of the deformed shape from the live load (pedestrians) is 79.5mm (L/1094). In the further phases of the designing of the structure, the problem from this displacement (79.5mm) can be solved by pre-camber where the longitudinal drainage of the bridge is resolved. The pre-camber can be used for obtaining the final form of the structural system, where the requirements for the serviceability of the bridge are met.

In figure 5 are the deformed shapes of the different analytical model through all the stages of the erection of the steel structure, taking into consideration the previous history of loading, and the final shape at every different step.

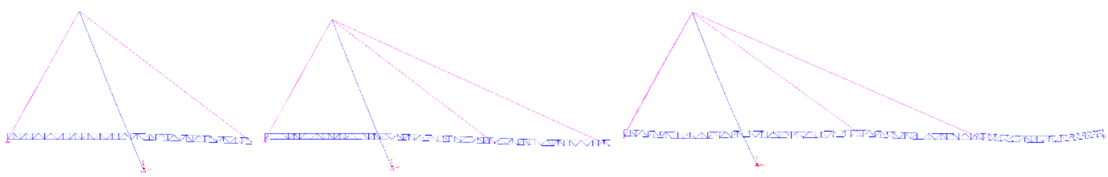

Fig. 5. Deformed shapes at different stages obtained with method 2

Moreover, results from same characteristic points of interest for comparison to the other analytical approach are given in Table 2. The results are for the maximum values of the displacements δs, forces N_{Ed} and stresses σ_{Ed} from all stages of the analysis for this method.

Title	δ_s [mm]	**Title**	N_{Ed}, σ_{Ed} [kN, N/mm2]
Top of pylon	8,6	Top chord	-1470.83
Third support – cable	23.9	Bottom chord	-2110.46
Fourth support - cable	32.2	Cable 1	+1601.50
Max. displacement	79.5	Cable 2	+975.33
		Cable 3	+2083.76
		Stress in pylon	146.70

Table 2. Displacements and forces

4. COMPARASION OF RESULTS

The results are made to show the difference of method 2 in reference to method 1, where the displayed results are the difference in percentages of method 2 compared to method 1, according to Eq. (1).

$$-\Delta = \frac{R_{M1} - R_{M2}}{R_{M2}} * 100[\%] \tag{1}$$

Where, R_{M1} is results from method 1, R_{M2} is results from method 2.

Title	**Δ (%)**	**Title**	**Δ (%)**
Top of pylon	-61.20	Top chord	-23.10
Third support – cable	-38.30	Bottom chord	-19.03
Fourth support - cable	-24.77	Cable 1	+3.72
Max. displacement	+10.10	Cable 2	-8.62
		Cable 3	-4.48
		Stress in pylon	-16.38

Table 3. Comparison of result differences obtained with the two methods

In Table 3 the results conclude that there are significant differences in the behaviour of the same structure analysed by the two different methods.

The pylon in the second method is less displaced for 61.2% than the pylon from the first method. The displacement at the third support analysed by method 2, where the second cable meets the truss, is for 38.30% smaller than the model analysed by the first method. The same is and for the fourth support, where the first cable meets the truss, where the displacements from the second method are smaller for 24.77% than the first method. The maximum displacement at the last span, between the first cable and the last support, is for 10.10% bigger than the one analysed by method 1. Even so, this displacement meets the requirements for the serviceability limit state. So it can be concluded that there are remarkable differences in the behaviour of the same structure analysed by the two different methods.

The maximum axial force at the top chord of the truss for the second method is smaller for 23.10%, and the bottom chord for 19.03% than the forces analysed in method 1. The same applies for the axial forces in the cables, where the differences aren't that large, for the first cable is bigger for 3.72%, the second is smaller for 8.62% and the third cable is smaller for 4.48%. Also, the total stresses, at the most unfavourable point at the pylon, are smaller for 16.38%.

All of above differences are result from the different approach of the analysis method and are due to more realistic, and also more demanding modelling applied with method 2, where the methods of erection of the bridge's steel structure are considered. In this particular case, at every stage, the length of the cables is corrected in the most favourable way for the positive behaviour of the structure.

5. CONCLUSION

The paper deals with analytical results and forces obtained with two different models applied for designing pedestrian bridge steel structure, the first method considers the whole structure, while the second approach analyses the staged construction i.e. stages of execution, with adjusting the cables through the stages, or at the end of each stage.

Evidently, the results are in favour of the analytical approach given in method 2, where benefits for the positive behaviour of the structure, for the serviceability limit state (SLS) and for the ultimate limit state (ULS), are almost in every stage.

It can be concluded that the analysis that takes into consideration the stages of the structure, with adjusting the cables through the stages, or at the end of each stage (method 2), can be more effective than the analysis for the whole structure (method 1). This also represents the real behaviour through all stages of erection and serviceability of the cable stayed pedestrian bridge.

Although it is more time consuming and engineering challenging, method 2 is more effective and represents the real behaviour through all stages of erection and is, as such, recommended for application in the structural analyses.

REFERENCES

[1] Chubrinovska A. (2017) "Cable stayed pedestrian bridge at river Vardar", Bachelor thesis.

[2] Cvetanovski P. (2012) "Suspension and cable stayed structures, lectures", GFS.

[3] Cvetanovski P. (2014) "Steel and composite bridges, lectures", GFS.

[4] EN 1993-2: "Eurocode 3 - Design of steel structures, Part 2: Steel bridges, European Committee for Standardization", (2006).

[5] Filipovski A. (2000) "Basic of steel structures", Vol. 2, Napredok, R. Macedonia.

[6] Gimsing N. J., Georgakis C. T. (2012) "Cable Supported Bridges, Concept and design, Third Edition", Department of civil Engineering, Technical University of Denmark, A John Wiley & Sons, Ltd, Publication.

[7] Guide to the Erection of Steel Bridges, BCSA, Publication Number 38/05, (2005).

[8] Hayward A., Sadler N., Todroff D. (2002) "Steel Bridges, A Practical Approach to Design for Efficient Fabrication and Construction", BCSA, Publication Number 34/02.

[9] Steel Bridge Group: Guidance Notes on Best Practice in Steel Bridge Construction, Fifth Issue, The Steel Construction Institute, March (2010).

[10] Technical guide Footbridges, assessments of vibrational behaviour of footbridges under pedestrian loading, Published by Setra, AFGC, October (2006).