Further Numerical Analysis on Composite Steel Concrete Structural Shear Walls with Steel Encased Profiles

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Abstract: - Numerical analysis were made on composite steel concrete structural shear walls with steel encased profiles to understand the theoretical behavior of the element in order to compare the results with those revealed by the experimental model. Composite steel concrete structural shear walls with steel encased profiles are a good alternative for high rise buildings that require considerable large lateral load resistance and strong axial load capacity. The encasement of the steel shapes in concrete is applied primarily for the following purposes: flexural stiffening and strengthening of compression elements; fire protection; potentially easier repairs after moderate damage; economy with respect both to material and construction. Construction and composite construction as well, has an important role to play in delivering sustainable development because of its contribution to national economy, and the significant environmental and social impacts that buildings can have. Scarce information about nonlinear behavior of composite steel concrete structural shear walls with steel encased profiles is available. The purpose of this work is to present numerical analysis on specified elements with different height/length ratios, for predicting nonlinear behavior, stress distribution, crack distribution, structural stiffness at various loads, and load bearing capacity of the proposed element.

Key-Words: - composite construction, shear walls, numerical analysis, sustainable construction

1 Introduction
Composite construction by steel and concrete are used in worldwide almost as soon as the two materials became available for structural engineers. Since the beginnings composite construction is in continuous progress, every high rise building that rises up to the sky, being the result of a continuous research work in all developed countries. In construction industry, sustainability is seen as a way in achieving sustainable development. Between the factors that influence the construction sustainability are: energy conservation, pollution prevention, resource efficiency, system integration and life cycle costing. From this point of view, composite construction can be included to sustainable construction, because is one of the approaches in achieving a reasonable level of impact on factors specified above. For example in composite construction the resource efficiency factor is achieved by the perfect use of the principal virtues of materials: the tensile strength of steel and compressive strength of concrete.

2 Theoretical aspects regarding composite steel concrete shear walls
The European standard EN 1994-1-1, Eurocode4: Design of composite steel and concrete structures: general rules and rules for buildings describe the principles and requirements for resistance, serviceability and durability of composite steel concrete structures. The simplified design method for composite compression members, which is limited to doubly symmetrical and uniform cross section along the element length gives the plastic resistance to compression of a composite cross section fully encased steel section as:

$$N_{pl,Rd} = A_{sa}f_{yd} + 0.85A_{c}f_{cd} + A_{s}f_{sd}$$ (1)

where $A_{sa}, A_{c}, A_{s} =$ cross sectional areas of structural steel, concrete and reinforcement of the composite cross section respectively; $f_{yd} =$design value of yield strength of structural steel; $f_{cd} =$ design value of compression strength of concrete; $f_{sd} =$design value of yield strength of reinforcement. The plastic moment resistance of a doubly symmetric composite cross-section may be evaluated as follows:
\[ M_{pl,Rd} = f_{yd} (W_{pa} - W_{pan}) + 0.5 f_{yd} (W_{pc} - W_{pcn}) + f_{yd} (W_{ps} - W_{psn}) \]  
(2)

where \( W_{pa}, W_{pc}, W_{ps} \) = plastic section modulus for steel section, concrete and reinforcement of composite cross section respectively (for the calculation of \( W_{pa} \) the concrete is assumed to be uncracked; \( W_{pan}, W_{pcn}, W_{psn} \) = plastic section modulus of the corresponding components within the region of \( 2h_n \) from the middle line of composite cross section for steel section, concrete and reinforcement of composite cross section respectively; \( h_n \) = depth of the neutral axis from the middle line of cross section.

The resistance of a cross section to combined compression and bending may be calculated taking account of the design shear force \( V_{a,Ed} \) as follows: if the value of \( V_{a,Ed} \) exceeds 50% of the design shear resistance \( V_{pl,a,Rd} \) given by (3), the influence of shear force is taken into account by a reduced steel strength with the factor \((1-\rho)\) where \( \rho \) is given in (4):

\[ V_{a,Ed} = A_e (f_{yd} / \sqrt{3}) \gamma_{M0} \]  
(3)

\[ \rho = (2V_{a,Ed} / V_{pl,a,Rd} - 1)^2 \]  
(4)

where \( \gamma_{M0} \) is partial factor for structural steel applied to resistance of cross section.

3 Nonlinear analysis

3.1 Nonlinear behavior

The nonlinear behavior of a structural element can arise from different causes, between them are geometric nonlinearities, material nonlinearities.

The geometric nonlinearities are caused due to large deformations experienced by structures, which can cause geometric configuration changing. Nonlinear stress-strain relationships are a common cause of nonlinear structural behavior. Many factors can influence material's stress-strain properties, including load history (as in elasto-plastic response), environmental conditions (such as temperature), and the amount of time that a load is applied (as in creep response).

3.2 Reinforced concrete model for plane stress state

A phenomenological approach to concrete failure may be based on various classical criteria for yielding and failure of an isotropic material. Of course these criteria are suitably modified as to account for the different values of the compressive and tensile strength of concrete. Although all yielding and failure assumptions (apart von Misses) incorporate the different compression and tensile behaviors. Therefore, a combined criterion such as Cervenka together with von Misses criterion for compression was used.

The finite–element modeling of cracked concrete was achieved with distributed cracks. The reinforcement is supposed uniformly distributed. At material level, the stiffness matrix may be obtained by superposing the concrete and the reinforcement matrices.

3.2 Nonlinear analysis software

The software called BIOGRAF is aimed to analyze reinforced concrete and composite steel-concrete elements in plane stress state. The two dimensional non-linear analysis is performed using incremental-iterative procedure (Fig. 1).

![Fig.1 Incremental procedure diagram](image)

An incremental approach is adequate in like cases for describing the transition from one working stage to the next (load history analysis) within each loading step an iterative procedure is used. The software gives in all the elements, in all load steps the displacements, stresses and strains in concrete and steel and the physical state of the finite element (cracked, uncracked, plastic state, crushed).

4 Composite steel-concrete shear wall analyses

4.1 Model presentation

Three proposed 1:3 scale elements were designed using the principles from the existing codes that make references to composite steel concrete elements. The three elements are different by length /height ratios, being named 1:3, 1:2, 1:1, which represent the ratio value. The models are in study in a program which purposes to predict nonlinear behavior, stress distribution, crack distribution, structural stiffness at various loads, load bearing capacity of different types of composite steel-concrete shear walls. More types of walls are intended to be studied, which can be different by the arrangement of the steel shapes on the cross section.

\[ \Delta \]  
\[ D_{s,d} \]

\[ S = S + \Delta S \]

\[ d = d + \Delta d \]

\[ D_{s,d} \]
of the wall, the possible existence of holes on wall elevation, different length/height ratios. The proposed elements have a 1000 mm length and 100 mm depth, the height resulting by length/height ratios as 3000mm, 2000mm and 1000mm. Every element has an encased steel profiles by 70 x 70 x 5 mm rectangular holed tubes connected with the concrete by Ø12 mm shear stud connectors with 70 mm length. The reinforcement is made by vertical bars Ø10/100mm and horizontal bars Ø8/150mm.

The confinement zone is made by Ø8/150mm struts which hold together for longitudinal reinforcements from the ends of the element. Both vertical and horizontal reinforcements placed on both sides of the concrete wall and connected together with ties Ø8/400/450mm. The concrete used is C20/25 class, the reinforcements are made by steel S355 and the structural steel is Fe510. The details of the steel concrete composite shear wall are presented in Fig. 2.

The analyzed wall is a cantilever subjected to horizontal loads applied as incremental loads in the nodes from the top of the mesh. The mesh of the wall can be observed in Fig. 3, Fig. 4, in which are presented the crack distribution and the stresses.

4.1 Analysis results

The BIOGRAF software gives in all elements, in all load steps, the displacements, stresses and strains in concrete and steel and the physical state of the finite element (cracked, uncracked, plastic state, crushed).

For a better view of stress distribution along element length AXIS program was used. Evaluating the physical state of the finite elements, for all three types of elements, the following conclusions are obtained.
For the element with 1:3 length/height ratio, the elastic limit of the concrete is attended for a force value \( F = 8.762 \text{ kN} \) and a corresponding displacement equal with 0.228 mm. From step number 18 it can be noticed that the concrete is cracked near the steel encased element, this can produce during the experiment concrete splitting which can cause the buckling of the steel element at a resisting force value lower that one obtained in the numerical analysis.

Therefore, a bigger attention has to be given to the confinement zone and to the shear connectors, to avoid buckling failure until bending or shear failure occur in the wall. The elastic limit of the element is at a force value equal to \( F = 149.162 \text{ kN} \). The displacement at the elastic limit of the element is 9.66 mm. The wall collapse occurs at the step 70 at a force value \( F = 189.462 \text{ kN} \), resulting a bending resisting moment equal to \( M_{pl,Rd} = 552 \text{ kNm} \), value with 14.5% bigger than one obtained with the simplified method from Eurocode4. The displacement recorded in post elastic stage is 6.16 mm. Also for the element with 1:2 length/height ratio, the collapse mechanism is specific to reinforced concrete failure, the concrete crashes when the reinforcement, including steel profile is in yielding.

For the element with 1:1 length/height ratio, the elastic limit is at a force value \( F = 139.42 \text{ kN} \) and the corresponding displacement value of 0.81 mm. The wall collapse occurs at a force value \( F = 396.82 \text{ kN} \), resulting a bending resisting moment \( M_{pl,Rd} = 396.82 \text{ kNm} \). This value is smaller with 17.6% than one obtained with the simplified method from Eurocode4. The displacement at failure is 2.35 mm. The collapse is specific to shear failure, conclusion that results also from the crack distribution obtained with the finite element program BIOGRAF.

\[ \sigma_{v take} = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + 2\mu(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1)} \]  

(5)

In the Figure 3 are represented the distribution of Von Misses stress in concrete, before failure of each type of element, stresses calculated with (5)

![Fig. 3 Von Misses isostresses in concrete](image-url)
concrete, which shows that the concrete is plasticized at the moment of collapse.

Figure 4 presents the crack distribution in all three types of elements at the moment of collapse. The evolution of the cracks is a normal one. For element 1:3 cracks are distributed uniformly on the element surface. The vertical cracks in the compression zone which appear from step 18 also show the splitting tendency of concrete near the structural steel. For element 1:2 first appears the bending cracks and at bigger values of the force are visible also the shear cracks. For element 1:1, which fails in shear the cracks are specific to this failure type, but in the compression zone appears also cracks specific to concrete splitting.

In the figures 5 ÷ 7 is presented a comparison between force displacement curve obtained with the nonlinear software and the theoretical curve for all three types of studied elements. It is obviously the decreasing of stiffness due to crack propagation in concrete at the beginning of loading for all three element types. The nonlinear behavior is more obvious as the length/height ratio increases.
4 Conclusions

The national and international literature studied show a poor level of knowledge in the field of using of composite shear walls at the multi-storey building. The observations on composite steel concrete structures subjected to important earthquakes made possible the improving of performances of structural system that use steel concrete composite shear walls.

Using the information presented above and the information from specific literature the following conclusions can be formulated:

- the information existing in literature is limited and the design formula are conservative;
- the research on composite steel concrete shear walls are in an ongoing process;
- in the lack of experimental information about the behavior of composite steel concrete shear walls, the codes refer to the composite columns;
- in order to clarify the design guidelines and to understand the real behavior of composite steel concrete shear walls, more experimental tests and structural analysis are necessary;
- the presented results from numerical analysis show different failure modes for different length/length ratios;
- the values of the bending resisting moment for the analyzed elements is approximate equal with the one obtained from the simplified method;
- the composite steel concrete shear walls have an important plastic resistance to compression, combined compression and bending and shear resistance;
- a special attention has to be given to the confinement zone and to shear stud connectors;
- experimental tests are needed in order to confirm the numerical analysis results.
- composite construction can be included to sustainable construction, because is one of the approaches in achieving a reasonable level of impact on factors that influence construction sustainability.

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