Parametric study in composite joints configuration

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Abstract. Composite structures showed higher stiffness than steel structures with similar ductility and also better performance to fire action. The global behaviour of the composite steel-concrete structure depends mostly on the behaviour of the joints. Many studies have demonstrated that composite joints exhibit adequate mechanical properties, such as strength, ductility and energy dissipation. The present paper is based on the study of the behaviour of the joints and their influence on the structure. The study involves a sensitivity analysis in the finite element program Abaqus 6.13. The analysis focuses on determining the parameters that significantly contributed both on the strength and stiffness of the joints and quantifying their weight in the final results. The analyses also provide information on the ductility of the connections under monotonic loads.

1. Introduction

Multi-storey buildings have been a favourite investor option for centuries and a challenge for engineers involved in materializing these projects. Due to the growth of the service sector, tourism and other sectors specific to the epoch, on the one hand, and due to acute managerial influences, such as the cost-benefit ratio, on the other hand, the demand for this type of structures is growing. Analysing the types of efficient, technical and economic structures for high-rise multi-storey buildings is therefore a major, permanent engineering concern.

Following the earthquakes in recent years, numerous studies have been carried out on various steel-concrete composite structures. Over time, joints have shown an important role in seismic applications. The lack of data for seismic design of composite joints leads to the situation where the designer has to choose whether or not to take into account the steel-concrete composite action. Compared to pure steelwork, composite joints provide greater moment resistance in a braced frame, through the tensile action of the slab reinforcement. However, they usually remain partial strength relative to the composite beam, and tests show that the rotation capacity at the enhanced moment is reduced. The rotation capacity is curtailed by several possible modes of failure, some are peculiar to composite joints, others are more likely because the tensile action of the reinforcement increases the balancing compression around the bottom flange of the steel section, thereby encouraging buckling [1].

The effect of behaviour of the joints on the distribution of internal forces and moments within a structure, and on the overall deformations of the structure, may generally be neglected, but where such effects are significant, they should be taken into account [2]. The joint connection inside the composite joint is numerical simulated in the finite element modelling program [3]. The complex method approach the design of steel and composite joints to the proven efficiency in terms of resistance and rotation capacity. This parametric study is based into a FE model, calibrated on experimental program on these type of joints, made at the Civil Engineering Faculty of TUCN [4].

1.1. Steel-concrete composite joints

The main objective of this work is to obtain a functional model by using the numerical modelling analysis, which reflects as accurate as possible the behaviour of the joint, by using the physical-mechanical characteristics of the materials.
As part of the component modelling in the FEM program, a fine mesh refinement was used, especially in the interconnection area, in order to better obtain the stress concentration and deformations of the assembly. The joints were modelled by using the finite element program Abaqus 6.13 [3] in which the physical-mechanical characteristics of the materials and the node geometry were taken into account. We highlighted the joints characteristics, meshing modes, contour conditions, and the chosen analysis method.

![Figure 1. The joints geometry](image1)

In the finite element analysis of the joints the purpose is to determine the resistance characteristics, the ductility, as well as the local effects occurring in joints subjected to hogging bending (Figure 2). The study was carried out to determine the bearing capacity of the joint, which is given by the strength of the weakest component. Considering the correct way in which the numeric model captures the joint behaviour, a parametric analysis was performed. In order to determine their inflection to the bearing capacity, rigidity and breaking ability of the composite steel-concrete joint configuration, we have to take into consideration the behaviour of each component, in particular.

The parameters considered were: the diameter of the joint, the thickness of the anchor plate, the steel profile, the quality of the steel and the number of connectors. The influence of their variation on the resistivity, stiffness and rotation ability characteristics was determined.

![Figure 2. Test setup of hybrid joints](image2)
2. Numerical modelling

The geometrical nonlinearity of the materials of all components making up the joints was taken into account as well as the effect of imperfections. In the complex model the modelling of the end plate, the steel profile, the connectors, and the concrete slab with three-dimensional finite elements were taken into consideration. The analysed joints were loaded increasing monotonous, the force being applied from the free zone of the composite beam (base model Figure 3).

The interaction between the parts was of the type General Explicit by having the following property: “hard contact”, on the surface and in the tangential direction (in the surface plane) and also a tangential behaviour with friction coefficient ($\mu = 0.45$).

The Abaqus 6.13 [3] finite element program uses numerical integration methods using the Gaussian quadrature for most elements in all of the element integration nodes. Elements can have normal or reduced integration, options that can influence the accuracy of the solution. The integration modes type C3D8 (8 nodes) are used for low integration to obtain stress and deformation, finite elements of order I or II. with partial or total interaction.

The type of analysis chosen for the numerical study is the one-step dynamic load analysis that simulates a quasi-static analysis. To diminish the dynamic effects of the model, we controlled the test by the duration and the mode of application of the imposed displacement, using the "Smooth step" amplitude curve.

An optimization process was made for each element in part, that makes up the joint, to determine a proper mesh discretization. In the analysis, the concept of Fracture energy was taken into account [3]. Element type S4R was used for modelling the behaviour of the reinforced concrete slab. This is a general-purpose conventional shell element which allows for transverse shear deformation to be taken into account. It also accounts for finite strains and arbitrarily large rotations [5].

The quasi-static analysis used in this paper is a particular case of dynamic analysis where the inertial effect is greatly diminished by applying the modelling rules. The most important parameters in this direction are:

- Application time (force, displacement),
- The amplitude of this request over the set time.

The application time must be long enough to avoid the shock effect. In order to monitor this, it is sufficient to check the total system energy and internal energy by percentage comparison. If the internal energy percentage is less than 3-5% of the total energy then the dynamic effect in the system can be considered as negligible.

The “concrete damage plasticity” (CDP) model of Abaqus [3] is used to describe the nonlinear material behaviour of concrete. The suitable materials and parameters were determined experimental. The purpose of this model is to present the effects of degradation associated with the failure mechanisms that are caused by cracking and crushing of the concrete.

![Figure 3. Numerical modelling of the joint.](image)
### Table 1. CDP (Concrete Damage Plasticity) parameters

| Parameter       | Dilatation angle | ψ  | ε  | f₀₀/f₀₀ | k  | μ  |
|-----------------|------------------|----|----|---------|----|----|
| Predefined value| -                | 0.1| 1.16| 0.667   | 0  |    |
| Value considered| 38               | 0  | 1.6 | 0.667   | 0  |    |

The steel characteristics are used from the different types of elements that makes up the joint obtained from the experimental tests of the specimens.

The modulus of elasticity (E) has a value of 210000N/mm², Poisson’s coefficient (0.3) elastic level. A design response that calculates the von Misses stress was use at the maximum value of the stress within a region of the model [3].

### Table 2. Steel properties

| Density (M) | Modulus of elasticity (E(N/mm²)) | Poisson coefficient | f₀₀/f₀₀ | f₀₀/f₀₀ |
|-------------|----------------------------------|---------------------|---------|---------|
| 7800        | 20000                            | 0.3                 | 1.2     |         |
| 7850        | 21000                            | 0.3                 | 0.80    |         |

- The results obtained by the FEM analysis are showed in Figure 4. Stress concentration in the joint configuration.

![Figure 4. Joints stress concentration.](image)

- The results obtained by the FEM analysis are showed in Figure 5. The ultimate bearing capacity and also the state of stress concentration in each element.

The joints deformations and stress concentrations, observed on the numerical analysis (Figure 5), allow a better perception of the behavior of these joints. Due to the obtained results the stress concentration is highlighted by transmitting the effort between the connected parts.
3. Parametric study

A parametric analysis in the finite element program Abaqus 6.13 [3] was conducted for this study. The analysis focuses on determining the parameters that significantly contributed both to the strength and stiffness of the joints. The main purpose is to minimize the weight of an element of the joint staying lower than allowable stress and displacement criteria.

The parameters that make up the moment-relative rotation curve define its behaviour (Figure 6).

The first component that started the parametric study is the longitudinal reinforcement of the composite steel-concrete slab.

The ability of the rotation of the joint is obviously limited by the elastic and mechanical properties that make up the connection. These properties define the ultimate strength of the joint that controls the imposed rotation to which it can grow.

The results obtained after the numerical analysis is presented in Figure 7, in terms of Moment-rotation curves.

The parameters considered were:
- Reinforcement bar from the steel-concrete composite beam
- Steel profile
• Number of connectors

![Figure 7. Moment –rotation curve obtained by parameterizing the Reinforcement bar.](image)

An increase in maximum rotation, as observed in Figure 8, compared to the joints made with the diameter of the Ø12 mm, in percentage is:

- With 4.89% using the diameter of the Ø10 mm reinforcement bar
- With 10.85% using the diameter of the bar Ø14 mm
- With 13.65% using the diameter of the bar Ø16 mm

![Figure 8. Moment –rotation curve obtained by parameterizing the steel profile.](image)

In Figure 9 is showed the increase in terms moment-rotation with:

- 3.02% using S235
- 3.62% using S355

compared to the S275
Figure 9. Moment –rotation curve obtained by parameterizing the number of connectors.

4. Conclusions

The presented paper is based on the study of the behaviour of the joints and their influence on the structure. The study involves a sensitivity analysis in the finite element program Abaqus 6.13. The analysis focuses on determining the parameters that significantly contributed both on the strength and stiffness of the joints and quantifying their weight in the final results. The analyses also provide information on the ductility of the connections under monotonic loads.

The failure mode of the joints appears by the fracture of the reinforcement, loss of anchorage (stress concentration in the end plates) failure of the shear connection in the superior part (concrete part) of the composite slab by bearing, and local buckling of the steel profile.

This type of joints is acting strongly related on the one hand, to the geometric configuration and on the other, to the particular behaviour of the materials.

The most pronounced influences on the joint response curves are given by the diameter of the reinforcement and the size of the steel profile. Also, large variations were obtained by parameterizing the number of connectors, the reference model being one with a stiffer reinforcement.

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