2nd Floor Joint Analysis of Block C, Granary Wharf

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ABSTRACT

Block C is part of the Granary Wharf development in Leeds City Centre. The design of the building involves the columns being offset at every floor by 165mm. The offset was predicted to make a large impact on how the building moves over time and as a result the elements of the building are heavily reinforced.

An analysis of a joint on the 2nd floor was carried out in order to establish how the offset affects the flow of force through the joints in the building and using this information to determine whether or not the elements are over reinforced.

A line and area model of the joint were created for the analysis and it was found that the line model overestimates the effects of the offset and the area model gives a clearer indication of how the forces flow through the joint. The area model showed that there is a varied distribution of stress across the column which causes both axial and bending stresses.

Using both the model outputs the reinforcement required in the joint was calculated. The reinforcement calculated for the columns using both models was 33% of the actual steel in the columns. The reinforcement calculated for the ring beam using the line and area model was 34% and 27% respectively, of the actual steel in the ring beam.

The large difference in reinforcement between the designs indicated that the limitations of the study would not make it possible to conclude that the elements in the joint are over reinforced. The limitations involved studying a localized joint, excluding lateral loading onto the joint and long term effects such as creep. The design in this study is the lower boundary of reinforcement required for the joint and further investigation would be needed to find out how the other factors not included in the study contribute to the amount of reinforcement in the elements.

Keywords: Offset; Sofistik; Restraints; Stress; Distribution; Limitations.

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INTRODUCTION

The purpose of this project was to investigate the behaviour of a reinforced concrete joint, which is part of a new high rise building in the centre of Leeds named Block C. The project was carried out in conjunction with Ramboll who were the design engineers for the building. A joint within the structure was modelled and analyzed using the computer program Sofistik. Using the information gained from the analysis the reinforcement in the joint was designed and then compared with the original used to construct Block C in an effort to see whether the large amounts of reinforcement in the building were necessary.

Block C is the Granary Wharf project's new build residential building and is a 22 storey circular structure with 14 columns and a ring beam at each floor with a shear core through the centre. The columns are offset at each floor by 165mm between the ground and fourteenth floor. This was to allow for the twisting nature of the architecture and was a better solution than having straight columns for four floors and then shifting them around with the facade.

The offset of the columns makes the load transfer from the beam and slab through to the foundations more complex. The analogy used to predict the behaviour of the building with the column offset was the idea that the columns were raking from the 22nd floor to the ground. This came from the assumption that the majority of force would flow diagonally through the columns. Using the concept of the raked columns the design engineer produced an extremely complex model of the global building which also took into account the 2nd order effects such as creep that would potentially have a large effect on Block C. The model indicated that the torsion, created from the shear force acting at a distance equal to the radius of the building from the centre, would make the building want to twist considerably.

An assessment of the effect the column offset had on a more localized area was not carried out during the design owing to time constraints. The building was modelled as a global structure with raked columns so the detail of how the forces actually flow through the column was not investigated. Ramboll were interested to find out about the behaviour of a single joint in the building under its own self weight and in particular how the force is transferred between the columns and ring beam and the stress paths they produce within the joint.

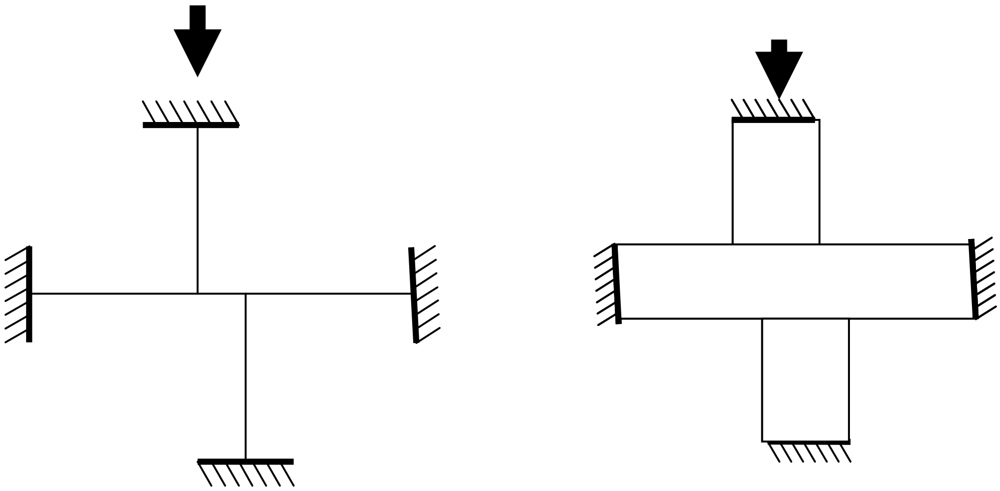
The project was delivered through four main objectives:

Objective one: Create two models of one joint in Block C using the finite element analysis software Sofistik.
Objective two: Analyze the behaviour of the joint through the model outputs.
Objective three: Design the reinforcement for the columns and beam in the joint.
Objective four: Compare and discuss the reinforcement design with the original design.

MODELLING THE SECOND FLOOR JOINT

The second floor joint was modelled in the finite element analysis programme Sofistik which was used to analyze both a line and area model of the joint to find out more about the behaviour of the forces as well being used for the reinforcement calculations.

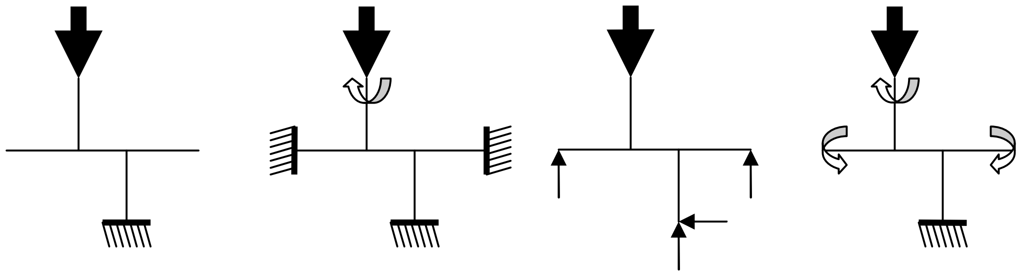
Creating both a line and area model of the joint was necessary because the offset when modelled as a line diagram shows that the axial force of the floors above would not carry straight through to the next column as in a conventional column grid. The force has to travel along the beam and into the column, which causes a moment within the joint. The magnitude of that moment and how it affected the rest of the joint was analyzed in the Sofistik programme. When the offset is modelled as an area it takes into account the reality that there is a direct path for the force to flow into the next column, although that part is only in a small section of the column. This is demonstrated in the figure below.



The load applied to one second floor column was calculated using information given in the brief by Ramboll and was used in the analysis of the joint.

The challenging part of creating the line and area models was finding the correct boundary conditions that would allow the models to represent reality as closely as possible. Although the joint was cut out of the structural grid the elements surrounding the joint had to be considered when predicting how it would move. The deflected shape was taken from the assumption that one column will buckle in both directions; therefore when cut at the half way point it shows no deflection. It was assumed the beam would deflect at the mid span which is where the joint was cut, therefore showing deflection at both ends.

Four initial boundary conditions were attempted for the line model, these are shown below.



All four cases had to be fixed at one end to ensure the model would be able to run the linear analysis. The first three cases did not replicate the deflected shape; however, the rotationally restrained upper column in case two was representative of reality and that condition was used on all three ends in the fourth case. This case was the most realistic and used for the model analysis.

When it came to choosing the restraints for the area model case four was used immediately, however, it did not behave in the same way as the line model for reasons which needed further investigation. Case four allowed the joint to move as if there were no restraints at all, therefore the rotational restraints were used at all three sides along with restraints in the x direction which then allowed the area model to move in a similar way to the deflected shape.

ANALYSIS OF SOFISTIK MODELS

The purpose of this paper was to analyze the outputs produced from running the models created of the second floor joint through a linear analysis using the Sofistik Structural Desktop. The paper investigates the movement of force through the joint in both a 1D and 2D analysis which helped in gaining a greater understanding of the impact the offset columns had on the stress paths through the elements. The information was then used later to design the reinforcement.

The analysis carried out by the Sofistik software is linear elastic, the results were therefore based on the assumption that the joint is behaving elastically and has not yet cracked. The complexity of the connection between the columns and beams meant that they could behave plastically, however, it was not possible to analyze whether that was the case within the time constraints. Instead it was assumed that the joint was behaving elastically under the applied load and the results reflect the behaviour of the joint.

The output gained from the line model explained that there would be an implication from the offset columns in how the force flows through the joint, however, the extent of this effect was overestimated by the simplicity of a 1D analysis. The output gained from the area model showed the effects of the column offset in much greater detail through a finite element analysis of the joint.

The principal stress distribution gained from the area model indicated that the stress distribution varied considerably across the columns. Both the area and line model implied that the beam either side of the connection was not greatly affected by the offset; slightly larger moments were induced in the beam around the column beam connection, but the offset did not affect the beam in the same way as the columns.

REINFORCEMENT DESIGN OF THE 2^{ND} FLOOR JOINT

This paper involved carrying out the design for the required reinforcement in the 2^{nd} floor joint using the information gained from the linear analysis. The reinforcement calculations showed that in spite of the unusual path of stress through the columns the reinforcement necessary to cope with the stresses was only 33% and 27% of the actual steel in the column and ring beam respectively. Just looking at those results indicated initially that the elements in the structure were too heavily reinforced, however, in reality there were many factors that needed to be considered that were not in this study such as the differences between the two model approaches, the implications of simplifying the joint for analysis, not taking into account long term effects such as creep and the exclusion of lateral loading onto the joint.

DISCUSSION OF THE LIMITATIONS OF THE STUDY

The main limitation of the study was the removal of the joint from the rest of the structure. The localized analysis did not incorporate the torsional effect that the whole building is subjected to under its own self weight. This factor could not be represented by the 2nd floor joint analysis because it has a cumulative effect over the whole structure which is caused by the column offset. All the limitations listed above worsen this effect which is the reason why the elements within Block C are so heavily reinforced.

Although the study has highlighted how a localized analysis can be inaccurate and not truly represent how the whole structure is behaving it is an essential part of understanding how and why the structure behaves as it does. When a global analysis is carried out on a building the amount of outputs that are created are huge and all the numbers can become confusing, so although it does give an idea of how the structure behaves as a whole, the more specific analysis of the elements gives a much clearer view of why the elements behave as they do when they are part of the whole building.

The limitations of the study mean that the investigation has produced a lower boundary reinforcement design for the elements within Block C. This is compared to the Ramboll design, which may have overestimated the effects of the offset columns through modelling them as raking down the building, which will have produced an upper boundary reinforcement design. It is likely that the ideal and most economic design for Block C will be somewhere between the two designs. This could only be confirmed by further investigation into the behaviour of the building.

FINAL CONCLUSION

This study did show how the offset columns affect the flow of force throughout the joints in Block C; however, on the larger scale they were not representative. It has been a useful tool in further understanding the complexity of the structure.

This study has laid the foundations for properly understanding the behaviour of Block C and with further investigation could result in finding a more economic design.

As a study on its own it has produced a lower boundary for the reinforcement design through understanding the localized effects of the offset columns on the joints throughout Block C.