CONCRETE WALL OPTIMIZATION IN USE OF A LARGE-SCALE BASE ISOLATED HOSPITAL BUILDING

N. Rokhgar¹, A. Gogus², T. Clifton³, M. Melek⁴, K. Chok⁵

ABSTRACT

Located in Istanbul, Turkey, Ikitelli City Hospital will be constructed on a building plot of approximately 1,000,000m². The building consists of three towers of varying levels ranging from 15 to 18 stories and six clinic buildings of approximately 4 stories above ground. The towers and the clinics share a 5-story podium with approximate plan dimensions of 300m x 400m, which is supported on nearly 2,000 isolators. Lateral load resisting system of the building is concrete core-walls-only, which yields in tremendous quantities of concrete utilization due to the large scale of the project. With the aim to minimize construction costs and to improve floor plan efficiency, a wall optimization study has been undertaken in which two input parameters were considered: (1) number of wall groups to be assigned the same thickness value to, and (2) number of wall thickness values to be considered. The output values of interest were: (1) building fundamental period, (2) shear demands and (3) concrete quantity. The aim was to obtain the most optimized concrete quantity which would provide sufficient lateral stiffness to the base isolated building. Based on the layout of the core walls, nine different wall groups and five different wall thickness values ranging from 400mm to 800mm were considered. Through implementation of some structural requirements (such as wall thickness not getting thicker with increase in wall elevation), a total of 180 possible wall thickness layouts were obtained. Individual Strand7 finite element models of the 180 different possibilities were automatically generated and analyzed through use of Grasshopper scripting. Modal analysis results and images as well as the concrete quantity for each of the models were uploaded onto a user-friendly web interface which the client had access to. The optimization study not only helped the client save on concrete quantity, but also enabled

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Concrete Wall Optimization in Use of a Large-Scale Base Isolated Hospital Building

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ABSTRACT

Located in Istanbul, Turkey, Ikitelli City Hospital will be constructed on a building plot of approximately 1,000,000m². The building consists of three towers of varying levels ranging from 15 to 18 stories and six clinic buildings of approximately 4 stories above ground. The towers and the clinics share a 5-story podium with approximate plan dimensions of 300m x 400m, which is supported on nearly 2,000 isolators. Lateral load resisting system of the building is concrete core-walls-only, which yields in tremendous quantities of concrete utilization due to the large scale of the project. With the aim to minimize construction costs and to improve floor plan efficiency, a wall optimization study has been undertaken in which two input parameters were considered: (1) number of wall groups to be assigned the same thickness value to, and (2) number of wall thickness values to be considered. The output values of interest were: (1) building fundamental period, (2) shear demands and (3) concrete quantity. The aim was to obtain the most optimized concrete quantity which would provide sufficient lateral stiffness to the base isolated building. Based on the layout of the core walls, nine different wall groups and five different wall thickness values ranging from 400mm to 800mm were considered. Through implementation of some structural requirements (such as wall thickness not getting thicker with increase in wall elevation), a total of number of 180 possible wall thickness layouts were obtained. Individual Strand7 finite element models of the 180 different possibilities were automatically generated and analyzed through use of grasshopper scripting. Modal analysis results and images as well as the concrete quantity for each of the models were uploaded onto a user-friendly web interface which the client had access to. The optimization study not only helped the client save on concrete quantity, but also enabled an open and efficient client communication.

Introduction

Ikitelli City Hospital will be developed on a large site at İkitelli district in Istanbul, Turkey. The Campus will include a main hospital building which consists of three specialty towers, six clinic buildings, a Facilities Management Logistics Building, an Administration, Teaching & Conference Building, a Physical Therapy & Rehabilitation Building, a Psychiatric Hospital, a central plant building and car parking. The specialty towers and the clinics share a common podium that includes three layers of basement which house the car parking (Figure 1). The whole podium together with the towers and the clinics above will be base isolated.
Gravity system of the base isolated building consists of 250mm thick flat slabs with 500mm deep drop panels that are 3m by 3m on plan between B03 and L2 levels; and precast concrete beams and hollow core planks from L3 to roof. Columns are cast-in place concrete over the building height with typical grids of 8.4 meters by 8.4 meters. Floor to floor height vary from 4 meters to 6.5 meters with typical being 4.3 meters.

Lateral load resisting system of the building consists of special reinforced concrete shear walls which resist 100% of the lateral loads in both orthogonal directions of the building. Due to the large-scale of the project, concrete volume optimization had been of utmost importance with the aim to minimize construction cost and improve floor plan efficiency at the same time. The optimization was conducted through development of an automated model generation and analysis process.

**Optimization Basis and Components**

**Basis**

Rule of thumb in selecting the isolator period is such that it be two to three times larger than the period of the fixed-base superstructure. The main aim in keeping a minimum ratio of 2:1 to 3:1 in the periods is to ensure dynamic decoupling exists. If the period of the superstructure gets close to the period of the isolators, the two systems would couple, acting as a single system instead of the superstructure acting as a rigid body on top of the sliding isolation plane.

A number of preliminary single degree of freedom studies were conducted on the hospital project to determine the most ideal range of isolation period. Selection of the period depends on
multiple factors including but not limited to (1) cost of isolators, (2) cost of superstructure, (3) architectural constraints on the superstructure, and (4) building performance.

Figure 2 provides a summary of the various isolation periods tested and the consequent performance of the superstructure associated with each isolation period. Cells highlighted in blue were determined to be the preferred combinations of period, and when the architectural constraints on the superstructure (such as maximum wall thickness) were taken into account, 4-sec. isolators governed over 3-sec. isolators and a target period of 1.75-sec. for the fixed-base superstructure was chosen to be the target period for the purpose of this optimization study.

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<th>Base Isolation Period</th>
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<th>Superstructure Period</th>
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Figure 2. Performance comparison of different periods of isolators

Components

In order to study all the possible thickness layouts, two components were chosen; (1) wall groups and (2) wall thicknesses. Nine different wall groups were identified based on similarity in plan geometry and wall height (Figure 3), and five different wall thicknesses were considered; 400, 500, 600, 700, and 800mm. ACI 318 [1] recommends use of 300mm as the minimum thickness for specially confined boundary zones of reinforced concrete walls. A lower bound of 400mm was chosen as the minimum wall thickness that could be utilized in the building based on some preliminary analysis results. Upper bound wall thickness of 800mm was determined by the architectural requirements.
Given the two input components ($w_t$; wall thickness and $w_g$; number of wall groups), the total number of possible thickness configurations ($n$) which can be utilized on the building is

$$n = w_t^{w_g}$$

(2)

Based on $w_t = 5$ and $w_g = 9$, this equation results in $n = 1,953,125$ different wall thickness layouts, which is practically impossible to evaluate. This number also includes thickness layouts that are structurally unacceptable/unpractical, such as the wall thickness getting thicker along the height of the building. Therefore, a logic chart together with an intelligent visual basic script was used to eliminate certain layouts as well as to insert the following conditions to further reduce the number of layouts to be studied:

1. Top wall group (light grey and light green in Figure 3) can only be 400mm thick
2. Bottom wall group (dark grey and dark green in Figure 3) can only be 800mm thick
3. Difference in wall thickness of a wall group below and above cannot exceed 200mm

Conditions (1) and (2) were determined based on preliminary analysis results; due to their elevation, top wall group was not contributing much to the lateral stiffness and strength of the building and therefore it made sense to keep them at the minimum thickness possible. The bottom group on the other hand, contributed the most to the lateral stiffness and strength of the building and thus we needed them to be as thick as possible. Condition (3) was implemented based on

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Figure 3. Wall groups represented by different colors.
constructability. With the implementation of these three conditions we were able to reduce the number of possible wall thickness layouts to 180, which is a much more practical number of structural models to build and evaluate for the optimization study than the original number of 1,953,125.

Model Generation and Analysis

Model Generation

Despite all the efforts to reduce the number of wall combinations to consider, 180 models were still too many to generate manually and therefore, automating the process of modeling, analysis and data extraction became the key focus. After considering different aspects of various software packages with respect to their analysis time, meshing capabilities and API features, Strand7 was selected for this automation task. At the same time, since the preliminary model for the hospital was already created in ETABS, the team had an opportunity to verify the analysis results, particularly the stiffness of the structure, using a different software.

In order to avoid going through the effort of modeling the entire structure from scratch, the geometry information along with frame sizes, wall thicknesses and all other necessary information was extracted from the existing ETABS model and uploaded to a central database using grasshopper. From there, using custom made Arup components in grasshopper, the information was retrieved from the database and an identical strand model was generated immediately which not only confirmed the results of modal analysis in ETABS but was also a key step in starting the automation process in strand (Figure 4).

![Mode 1](image1.png)

Mode 1
Period = 1.587 s
Direction = 100% UY

![Mode 1](image2.png)

Mode 1
Frequency = 0.628 Hz
Period = 1.592 s

Figure 4. ETABS model to Strand7 model transition
Analysis

After generating the first strand model and knowing the various wall thickness combinations under consideration, the automation process could start. A script was developed in grasshopper using Arup components and strand’s API that was able to copy the original model by the intended number of iterations (180 models in this case) and was then able to open each one of the models, change all wall thicknesses to the intended thickness combination of that particular iteration, run a modal analysis and find the first four periods of the structure. After the analysis was completed on all 180 models, the script could extract the analysis results into a CSV file for each model and eventually upload all of this information to a database for further analysis. This entire process took approximately 12 hours so it could be run over night and the team had access to all the results by the next day.

Having all the data required from these 180 models, another script was then developed to process all of this information on the database and based on a given target period (1.75 seconds in this case), choose the model that could achieve or surpass the target stiffness, by using the least “volume of concrete” in the walls. These thicknesses were then transferred to the Dyna model in order to run the non-linear time history analyses and verify that, besides satisfying the stiffness requirements, these thicknesses would also pass the strength criteria. Figure 5 summarizes this workflow. Besides helping the engineers identify the most optimized solutions, the results of this automation process was visualized in a web interface in order to easily engage the client in the decision making process and demonstrate why/how Arup believes these thicknesses will result in significant savings for the client without compromising the target performance of the building.

Figure 5. Model generation workflow
The Arup Optieering application (Figure 6) was built to provide structural engineers with an easy way to iterate and visualize analysis for concrete wall optimization, as well as to provide the client with an easy way to gain insight to the ongoing studies. The application was built using a template focused approach, in order to allow the engineers to easily spin up new instances of the application each time new analysis data became available. The engineer would supply a fresh data table and image set, along with a small csv that included desired functionality such as which parameters should be sliders, multi-selects, etc. This information would then be passed through a semi-automated process that would combine all of the necessary data with the application codebase in order to create a new static instance of the application.

Once a new instance of the application was created and deployed, it would then become available for the engineers and the client to explore the result set. The application allows them to search and filter the optimization options using sliders and multiselects that were created based on the specified configuration from the engineer. It also provides bubble charts that compare the selected parameter to the other metrics. The user can then select a specific wall configuration and dive deeper into the result set. The detail page includes analysis generated pictures as well as a descriptive list of all analysis metrics (Figure 7)
Figure 7. Detailed modal analysis results for one out of the 180 models on the webpage

**Evaluation of Results**

Using the Arup Optioneering interface, analysis results for the 180 models were compared. Based on the optimization study constraints set at the beginning of the study, wall concrete volume varied from 62,000 m$^3$ to 72,000 m$^3$ (Figure 8). Corresponding fixed based period of the structure was observed to be varying depending on the solution selected.

Figure 8. Wall Concrete Volumes

The design team selected solution number 151, with a wall concrete volume of 66,005 m$^3$ and a fixed based period of 1.73 seconds. Results of the various models could as well be easily post-processed through use of developed Grasshopper scripts (Figure 9).
Design team for Ikitelli City Hospital Project employed cloud based optimization methodologies to minimize construction costs and to improve floor plan efficiency. The aim was to obtain the most optimized concrete quantity which would provide sufficient lateral stiffness to the base isolated building.

1,953,125 possible wall thickness permutations was reduced to 180 by applying constraints to the optimization study. Remaining 180 design options were analyzed and results were compared on Arup Optioneering web platform. Optimization study enabled the team to reduce the wall thicknesses to a minimum without compromising the stiffness demands needed for the isolation system. The optimization study not only helped the client save on concrete quantity, but also enabled an open and efficient client communication.

References

1. ACI 318 (2011) Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary, American Concrete Institute, Farmington Hills, MI.

2. CSI ETABS Version 16.2

3. Strand7 R.2.4.6