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the BIM expert

SOIL – STRUCTURE INTERACTION
FLAC3D - MIDAS GEN DIRECT LINK

STUDIO colleselli &p.
INGEGNERIA GEOTECNICA

NEW MULTI-STOREY BUILDING IN MILAN

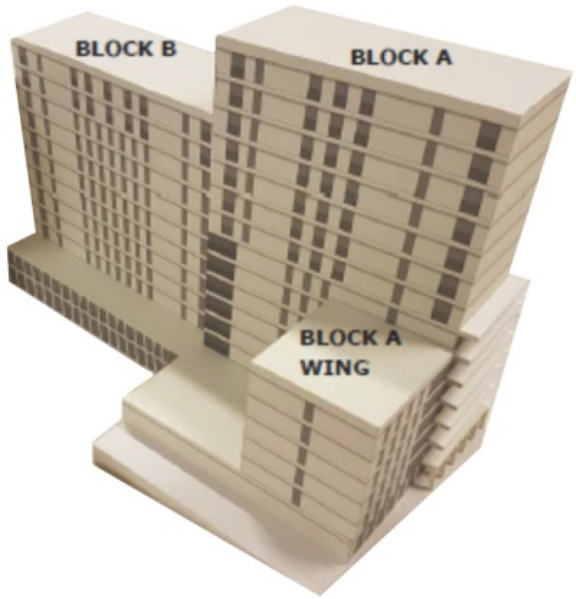
The building's reinforced concrete frame is divided in two main blocks: A and B

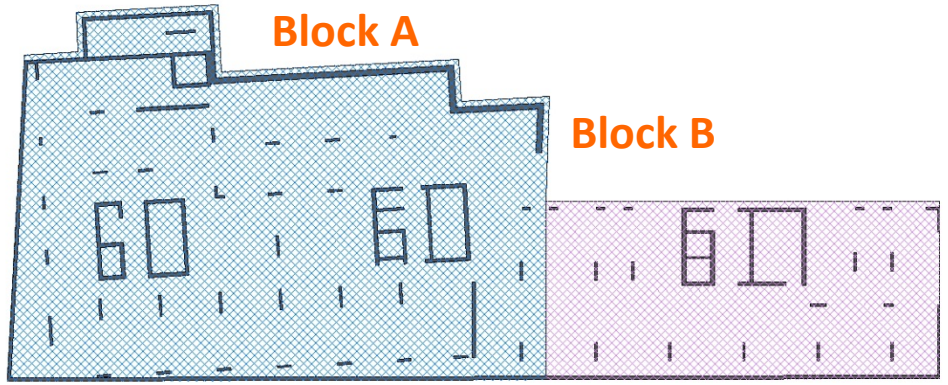
→ **Block A**

- 1 floor below ground level and 14 floors above (+ wing with 6 floors only above ground)
- total height ≈ 50 m
- irregular shape with length of 48 m and max width of 32 m
- foundation type: raft foundation reinforced concrete slab

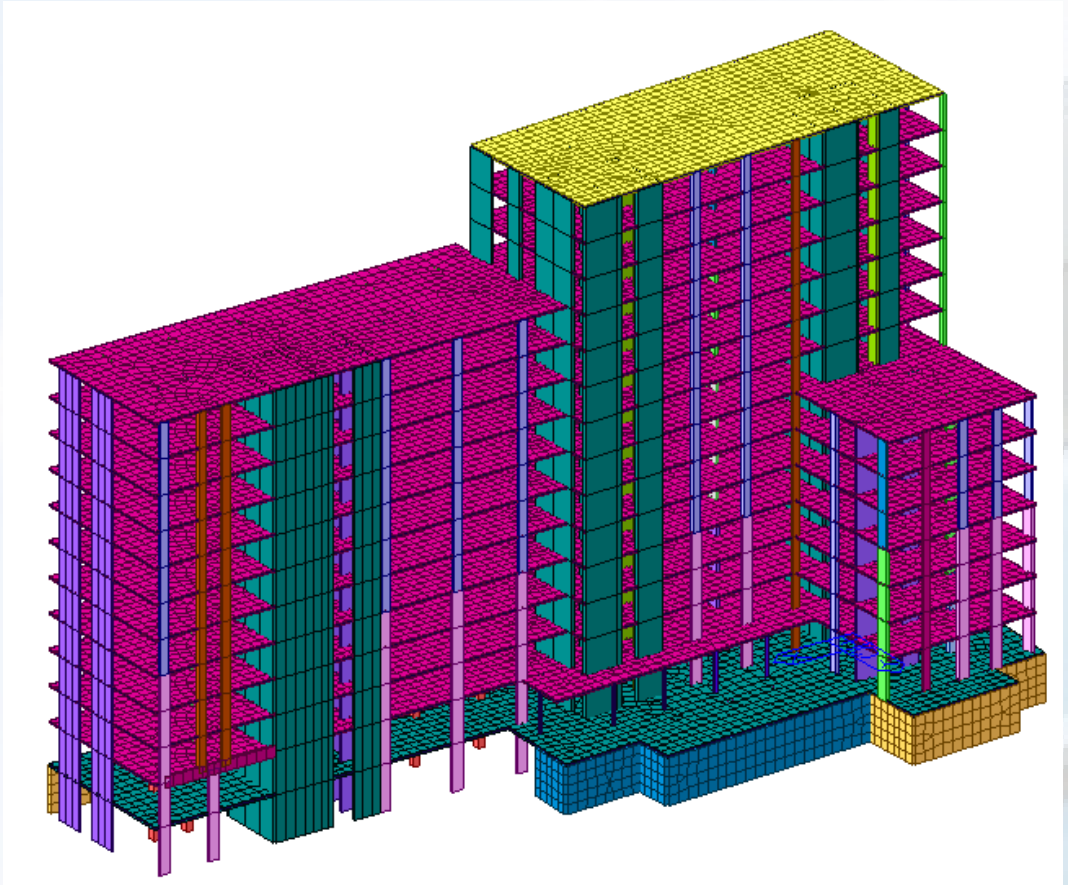
→ **Block B:**

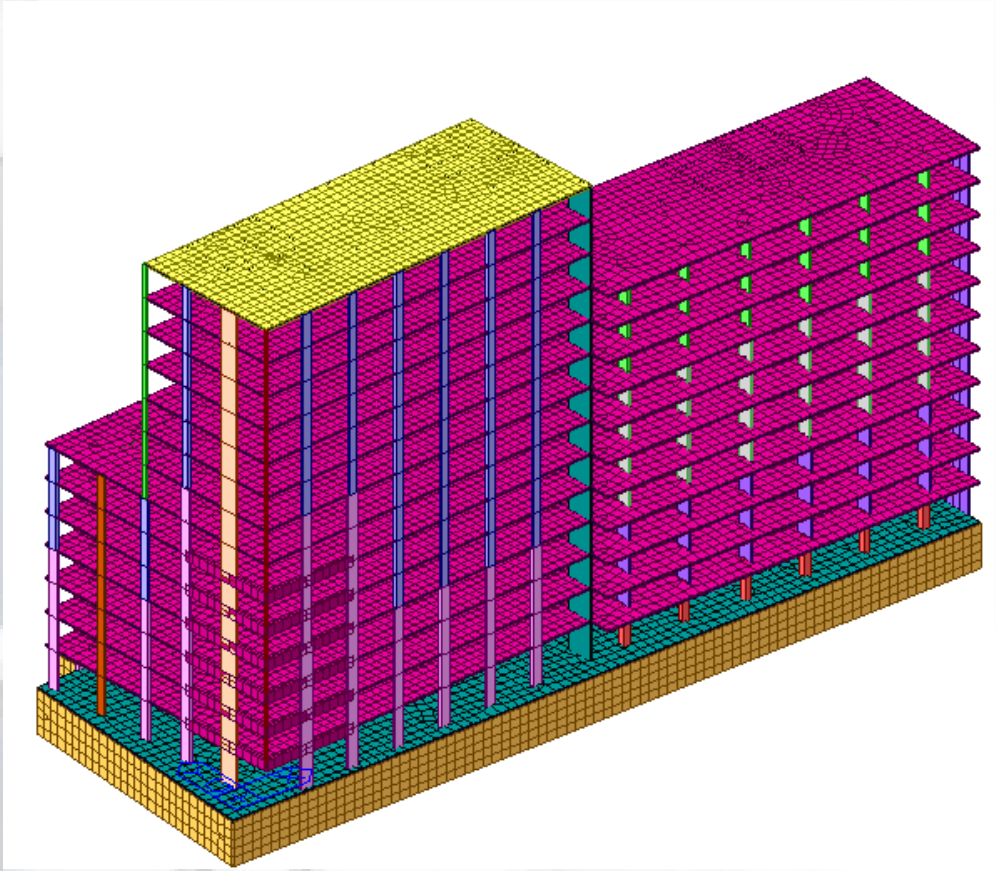
- 1 floor below ground level and 11 floors above
- total height ≈ 40 m
- rectangular shape about 15 m x 34 m
- foundation type: raft foundation reinforced concrete slab





Structural modeling of the building has been performed by finite element software MIDAS GEN.
Some images of the model:





The combined pile raft foundation (with bored piles or jet grouting columns) was presented with a preliminary design to reduce settlements in SLS conditions.

The proposed solution was:

- **adding significant cost on the overall budget**
- **delaying the time schedule for job completing**
- **impacting on site logistic and management**

Given the nature of the foundation soil and the structural requirements of the building, value engineering has been provided to ASSESS the possibility of a raft foundation with increased thickness WITHOUT PILES, with considerable SAVINGS (costs, time and site management).

For this purpose, a model with the FLAC3D code has been developed, to consider :

- the geotechnical soil profile according to site investigations →

- the UNLOADING-RELOADING effect due to the excavation for the basement →

- the contribution ("confinement") provided by the soil above foundation level outside the excavated area →

- the shape of the raft foundation →

- the stiffness of the raft foundation →

- THE STIFFNESS OF THE STRUCTURE above the raft foundation →

- THE REAL DISTRIBUTION OF THE LOADS ACTING ON THE RAFT FOUNDATION →

→ FOUNDATION SOIL

Geotechnical profile according to site investigation

	Soil type	Thickness	Level from	To	Unit weight	Buoyant unit weight	Friction angle	Cohesion	Young's Modulus	Young's modulus (unloading - reloading conditions)
	[-]	[m]	[m]	[m]	γ [kN/m³]	γ' [kN/m³]	ϕ'_k [°]	c'_k [kPa]	E [MPa]	E_{ur} [MPa]
Layer1	Man made	4.0	0.0	-4.0	19.0	9.0	27	0	6	18
Layer2	Medium density layer - Gravel with sand and silt	6.0	-4.0	-10.0	20.0	10.0	33	0	30	90
Layer3	Low to medium denity layer - Slity sand	3.5	-10.0	-13.5	19.0	9.0	30	0	12	36
Layer4	Medium density layer - Gravel with sand and silt	4.5	-13.5	-18.0	20.0	10.0	33	0	35	105
Layer5	Low density layer - Silty sand	3.0	-18.0	-21.0	20.0	10.0	31	0	15	45
Layer6	Medium density layer - Gravel with sand and silt	1.5	-21.0	-22.5	20.0	10.0	33	0	35	105
Layer7	Low density layer - Silty sand	2.5	-22.5	-25.0	19.0	9.0	29	0	8	24
Layer8	Dense layer - Gravel with sand and silt	10.0	-25.0	-35.0	20.0	10.0	36	0	50	150

→ UNLOADING-RELOADING DUE TO EXCAVATION

For a correct estimation of settlements it is necessary to consider the stress path (lithostatic conditions, unloading due to excavation up to 8 m, and reloading up to maximum stress due to design loads considering the multi-story building completed)

For the reasons above, the following have been applied:

→ The Plastic Hardening constitutive model (Shanz, 1998) has been adopted to model soil

Plastic Hardening is a hardening elastoplastic model with a Mohr-Coulomb failure criterion but with hardening surfaces that vary with the evolution of soil tensional state and that allows differentiation of soil behavior depending on whether it is in virgin loading conditions or recompression.

→ Excavation has been simulated, deactivating — after the preliminary geostatic phase (and before the activation of the structure) — a suitable set of elements representing the excavation area.

Outside this excavation area the land remains at ground level, contributing to the “confinement” of the building foundation soil.

→ MODELING OF THE STRUCTURE

To provide a the best estimation of the raft foundation settlement, we have considered:

- ***the shape of the raft foundation***
- ***the stiffness of the raft foundation***

- THE STIFFNESS OF THE STRUCTURE above the raft foundation →

- THE REAL DISTRIBUTION OF THE LOADS ACTING ON THE RAFT FOUNDATION →

THIS AS BEEN POSSBILE BY IMPORTING IN *FLAC3D* THE STRUCTURAL MODEL MADE WITH MIDAS GEN

→ WITH ALL ITS STRUCTURAL ELEMENTS: beams, shells and plates *(correctly interconnected)* to simulate slabs, pillars and floors connected with the raft foundation

→ WITH ALL ACTING LOADS (structural and non structural dead loads and variable loads in SLS quasi-permanent conditions)

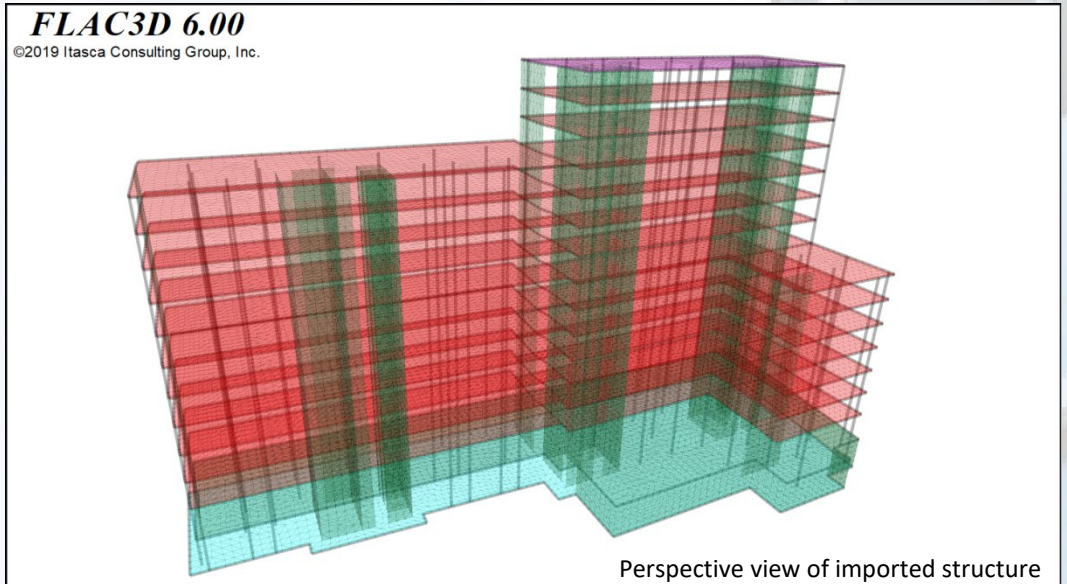
→ IMPORTING MIDAS GEN MODEL IN *FLAC3D*

The procedure for importing the MIDAS GEN model in *FLAC3D* has been implemented by HARPACEAS providing a "script":

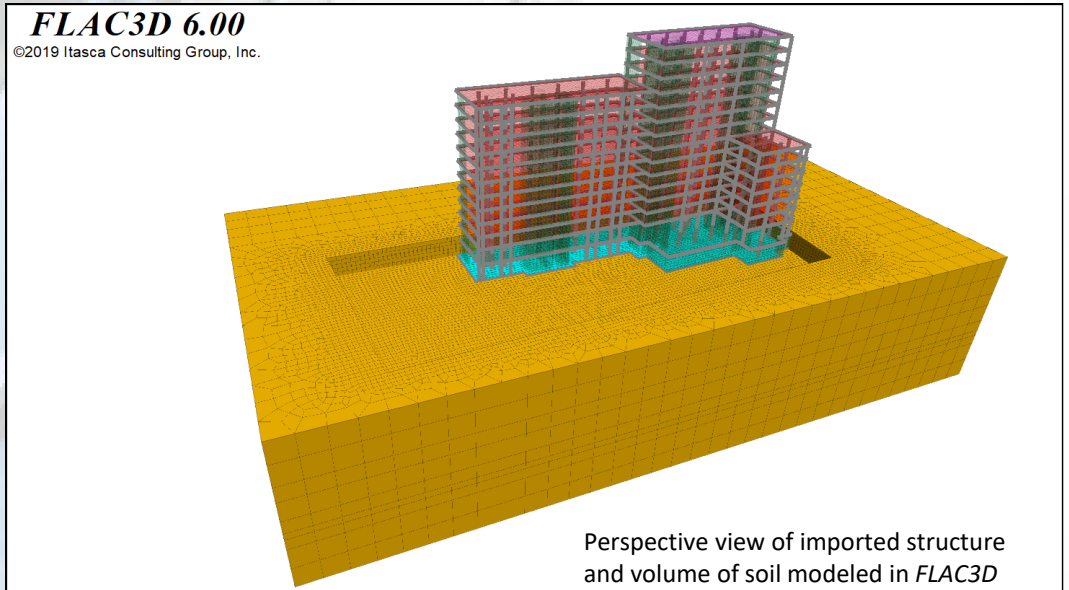
- the "script" reads *.mgt save files generated by MIDAS GEN and automatically translates all beams, shells and plates elements in corresponding structural elements "compatible" with the finite difference code *FLAC3D*: the entire structure is thus automatically recreated in *FLAC3D*.

- The connection between the slab shell (1.5 m thick) and *FLAC3D* grid (that simulates foundation soil) has been modeled using specific "link" elements.

- Structural loads in *FLAC3D* have been applied element by element using a spreadsheet.

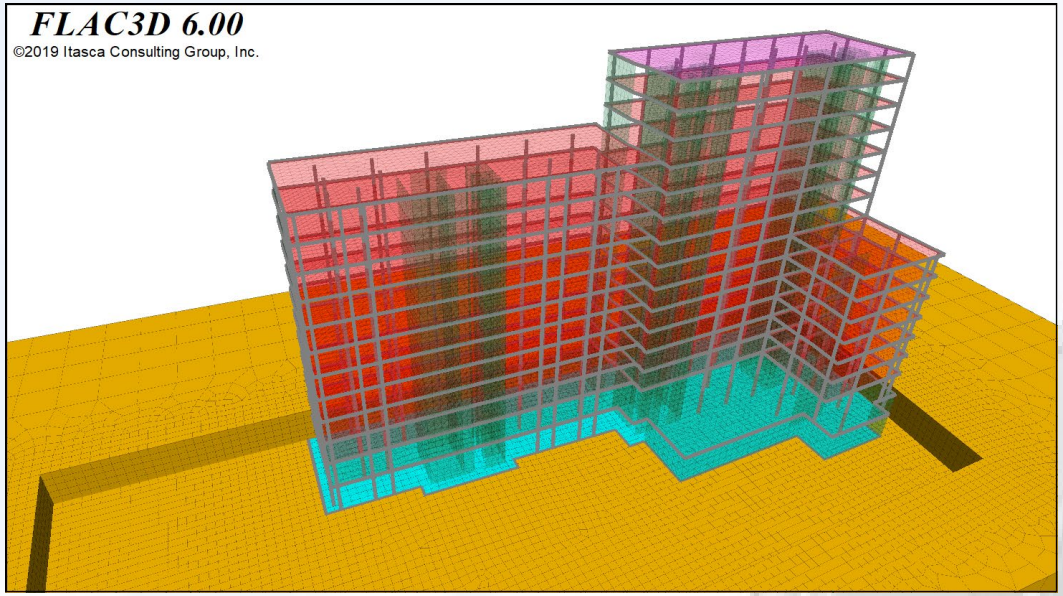


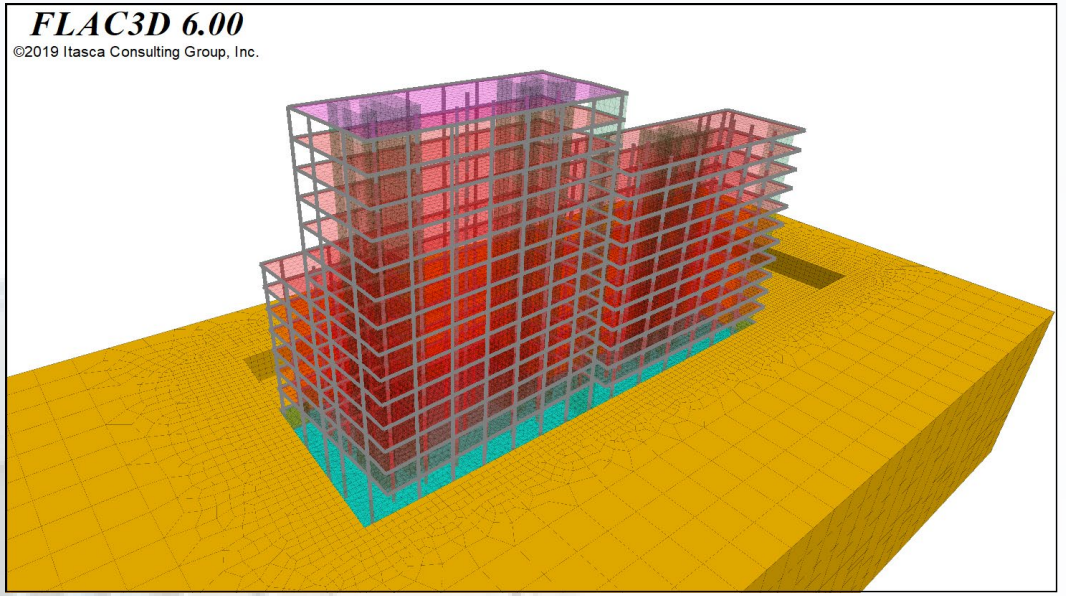
Perspective view of imported structure

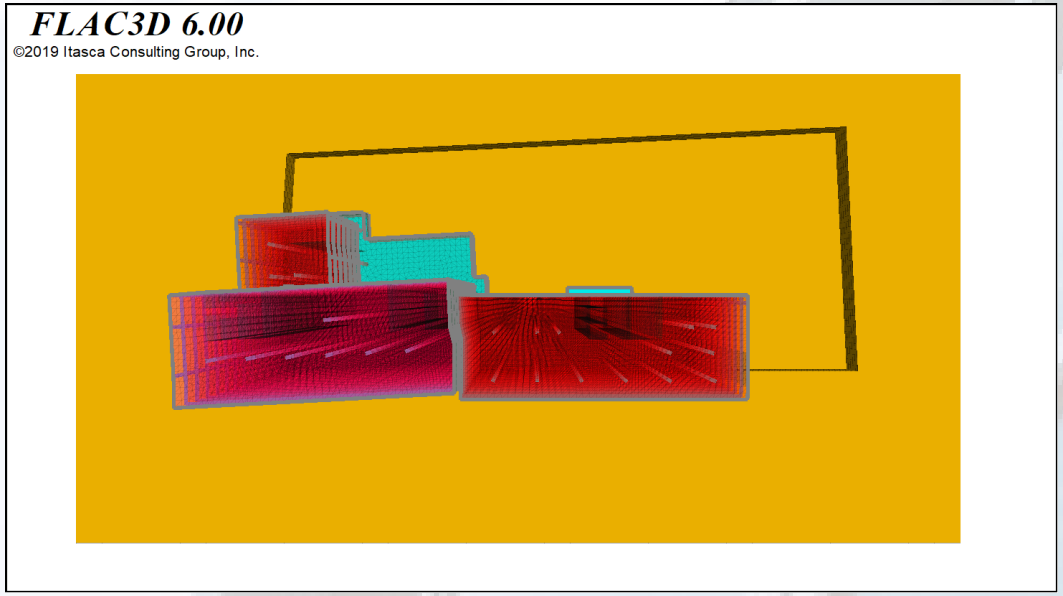


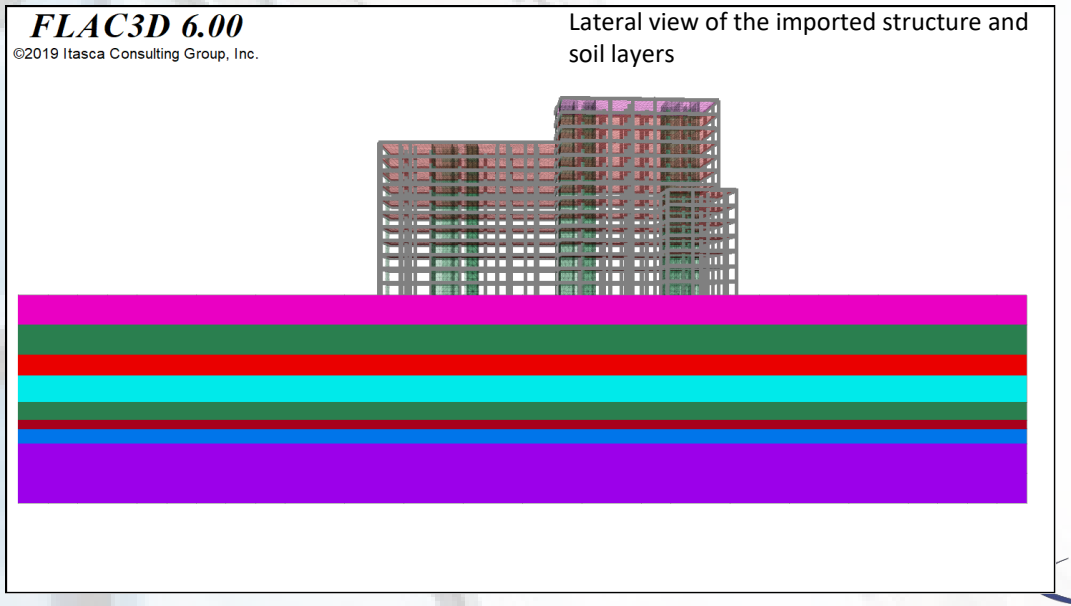
Perspective view of imported structure and volume of soil modeled in *FLAC3D*

IMPORT IN *FLAC3D* OF A MIDAS GEN STRUCTURAL MODEL









Lateral view of the imported structure and soil layers

RESULTS

Scope of modeling was the best estimation of settlements of raft foundation.

Considering the soil behaviour in unloading-reloading conditions, the shape and stiffness of the raft foundation including the effect of the structures of the building and the exact distribution of the loads acting on the foundation.

RESULTS:

→ **The maximum settlement is about 34 mm: given the nature of the soil settlements due to structural and non structural dead loads are immediate and develop during the construction of the building.**

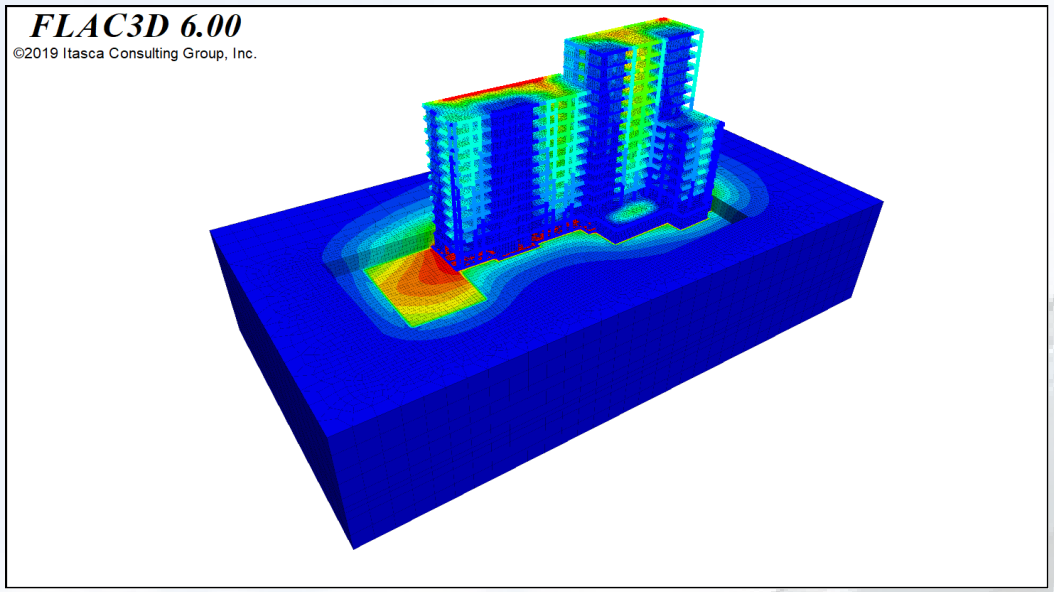
→ **Differential settlements are negligible (about 1 mm)**

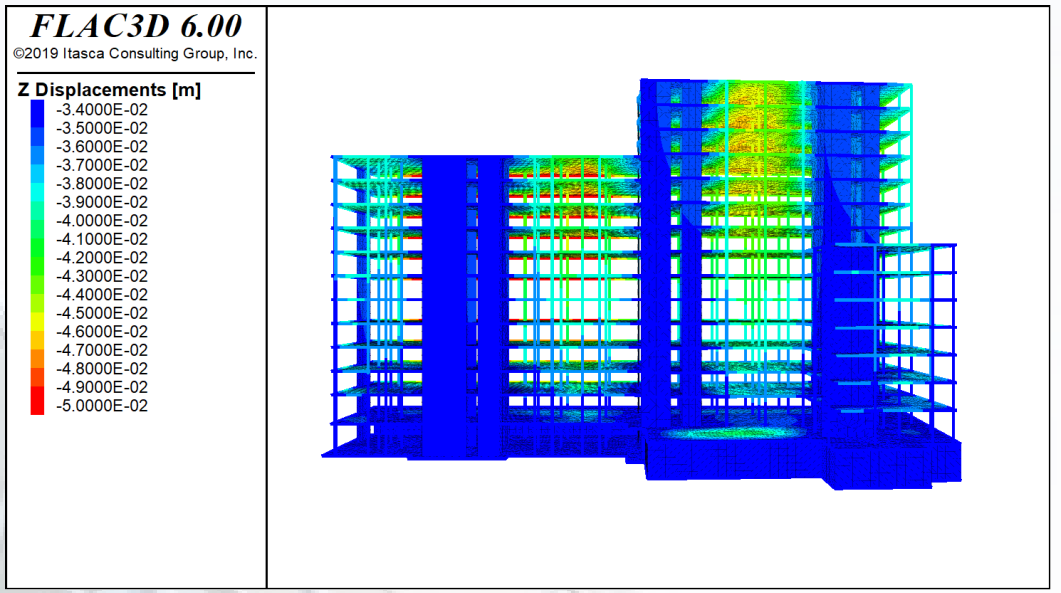
→ **Distortions and tilting are negligible too**

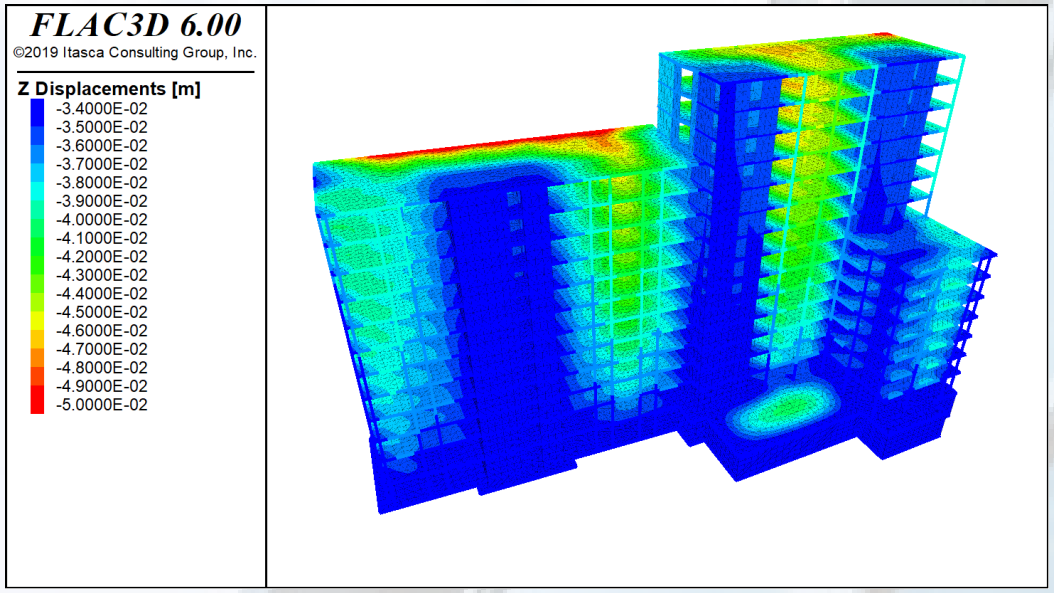
***FLAC3D* MODEL SHOWS THAT THE RAFT FOUNDATION AND THE BUILDING STRUCTURE HAVE A RIGID BEHAVIOR, WITH UNIFORM AND LIMITED SETTLEMENTS, WITHOUT DIFFERENTIAL SETTLEMENTS AND DISTORSIONS**

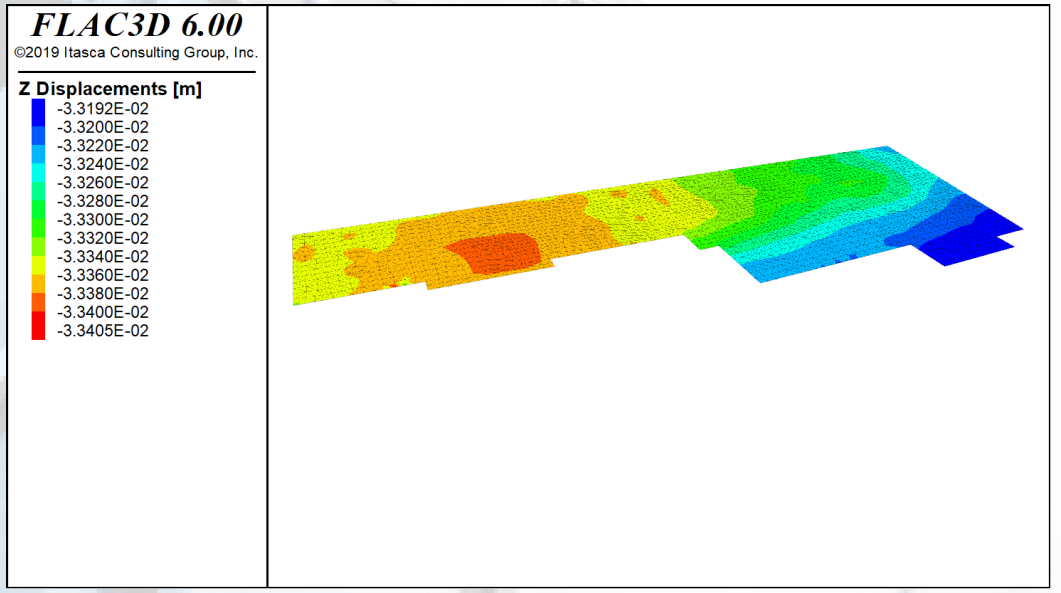
COMBINED RAFT FOUNDATION (WITH PILES OR JET-GROUTING COLUMNS) IS NOT REQUIRED TO REDUCE SETTLEMENTS IN SLS

IMPORT IN *FLAC3D* OF A MIDAS GEN STRUCTURAL MODEL





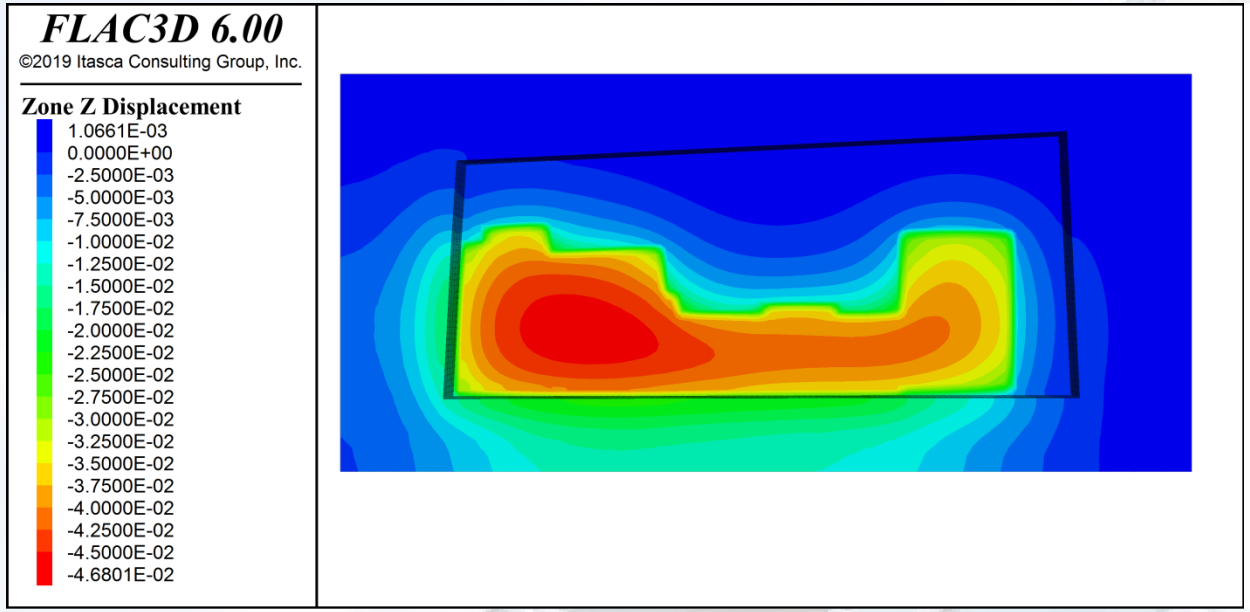


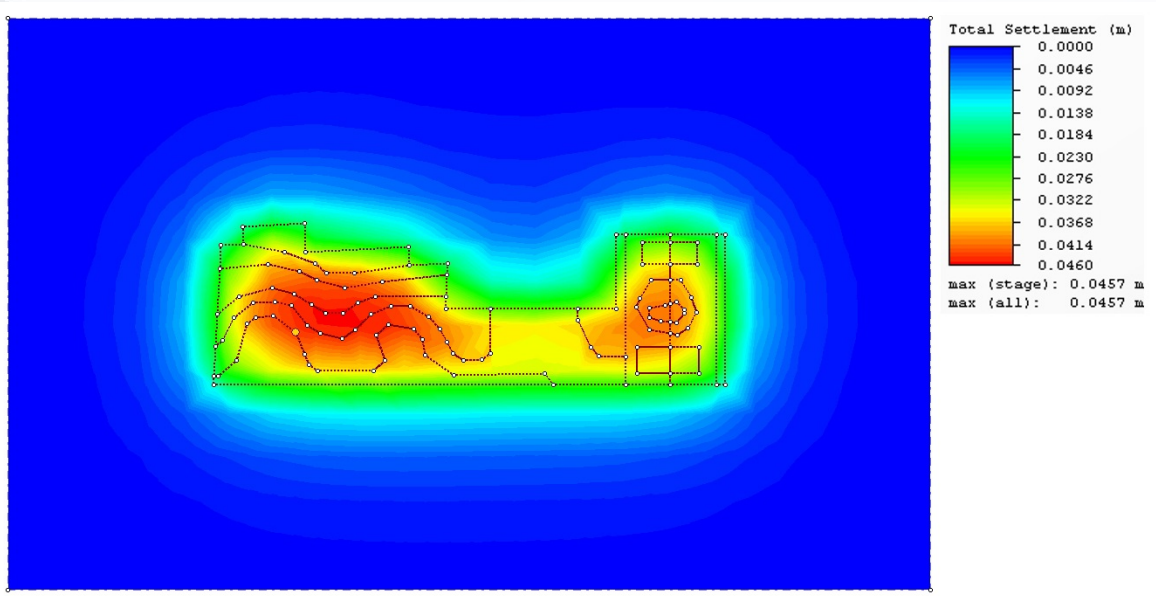


MODEL CHECK AND VALIDATION

The *FLAC3D* model has been validated by comparison with a "simplified" model based on Boussinesq approach.

Assuming an upper (flexible foundation) boundary, as the approach with the simplified model does not allow consideration of the raft foundation stiffness.





Both models (*FLAC3D* and the model based on Boussinesq approach), in the hypothesis of a flexible foundation, lead to the same distribution of settlements, with a maximum value of 46 mm and a differential of 20 mm.

→ *FLAC3D* model is validated

→ Thanks to the ability to import into *FLAC3D* the structure modeled with Midas Gen, it has been possible to consider its REAL STIFFNESS, which leads to estimate NEGLIGIBLE DIFFERENTIAL SETTLEMENTS