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The seismic isolated Stavros Niarchos Foundation Cultural Center in Athens (SNFCC)

Christos Giarlelis[a,b,*], Jared Keen[c], Evlalia Lamprinou[b], Victoria Martin[c], Gerasimos Poulios[b]

[a] Department of Civil Engineering, Aristotle University, Thessaloniki, Greece
[b] Omete SA, Athens, Greece
[c] Expedition Engineering, London, UK

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ABSTRACT

The recently constructed Stavros Niarchos Foundation Cultural Center (SNFCC), houses the National Opera and the National Library of Greece. In order for the structural design to meet the demanding architectural requirements as well as the high-performance seismic specifications that were set, a seismic isolation system was incorporated. SSI effects due to poor silty sands were an additional challenge. After presenting the design parameters and the choice of seismic isolation type, the paper focuses on the methodology for the seismic design. This, performed in three consecutive stages, includes simple analyses using single-degree of freedom model for initial scheming, dynamic response spectrum analyses for detailed design and non-linear time history analyses using two sets of selected earthquake records, semi-artificial and real ones, for verification of the response. The results demonstrate a good correlation between different analysis techniques and provide a valuable insight into the behaviour of two complex, seismically isolated structures under seismic loads. The problems and solutions resulting from the implementation of the seismic isolation are also briefly presented.

1. Introduction

The Stavros Niarchos Foundation Cultural Center (SNFCC) has been recently constructed in the bay of Phaliron in Athens and houses the National Opera and Library of Greece which started operating in 2017. The Foundation funded the project and commissioned executive architect Renzo Piano and a team of highly qualified engineering firms to design the various individual structures within the development. Structural and seismic design has been assigned to Expedition Engineering with local partner the firm Omete SA. The project has already earned a series of distinctions for its innovative design, including the 2016 structural award from the Institute of Structural Engineers and the nomination as the “best international project of the year” in the 2016 UK Building Awards.

The main structural challenges of the project are the very poor soil conditions, the high seismic performance expectations and the need to satisfy a demanding architectural concept. Therefore, the incorporation of a seismic isolation system of friction pendulum type was deemed necessary. This makes the project the third seismic isolated building project in Greece after the Onassis Cultural Center and the Acropolis Museum, (Anagnostopoulos [1], Huber et al. [2], Giarlelis et al. [3]). However the combination of scale, number of isolators, level of seismic demand and soil-structure interaction effects (SSI) make this project special. It should be also noted that in the aforementioned projects, in the absence of a national code, the IBC code provisions [4] were followed for the design of seismic isolation, while for the SNFCC, Eurocode-8 (EC8) [5], along with EN 15129 [6], were in effect and used for the first time in Greece.

This paper focuses on the methodology followed for the analysis and the design of the structures. The results, from the simplest approach to the more sophisticated ones, show good agreement, allowing a good insight into the dynamic behaviour of the buildings to gradually be gained. Structural choices and solutions to problems arising from the application of seismic isolation are also briefly presented as well as issues arising from the application of EC8.

2. Project description

Architect Renzo Piano envisaged the SNFCC, Fig. 1, rising out of the landscape which comprises of an artificial hill of smooth inclination. The cultural complex consists of various structures, the main ones being the seismic isolated buildings of the National Opera and Library of Greece. Both structures are nestled under the highest part of the hill with their green roofs being part of a large park designed by landscape architects Deborah Nevins & Associates.

* Corresponding author.
E-mail address: giarlelis@alumni.rice.edu (C. Giarlelis).

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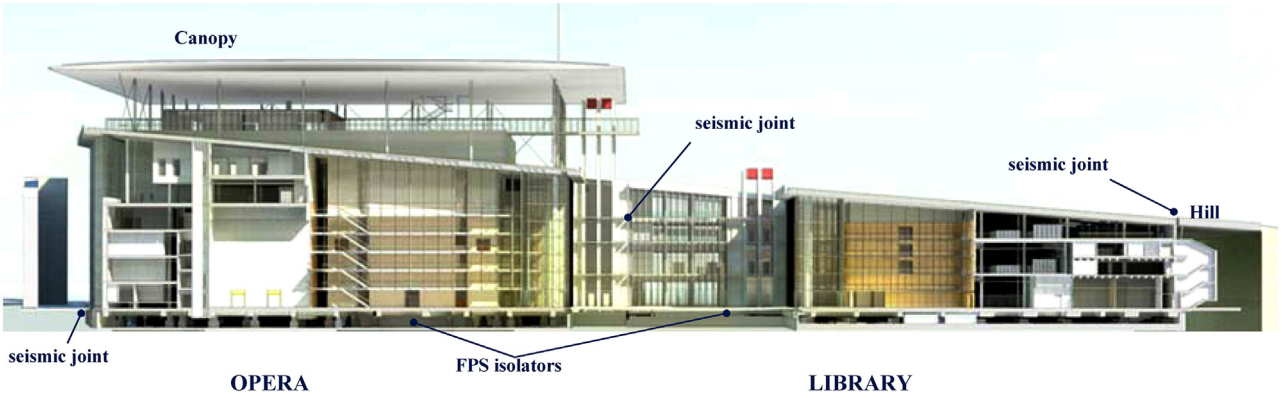

Fig. 1. Longitudinal Section of the Stavros Niarchos Foundation Cultural Center.

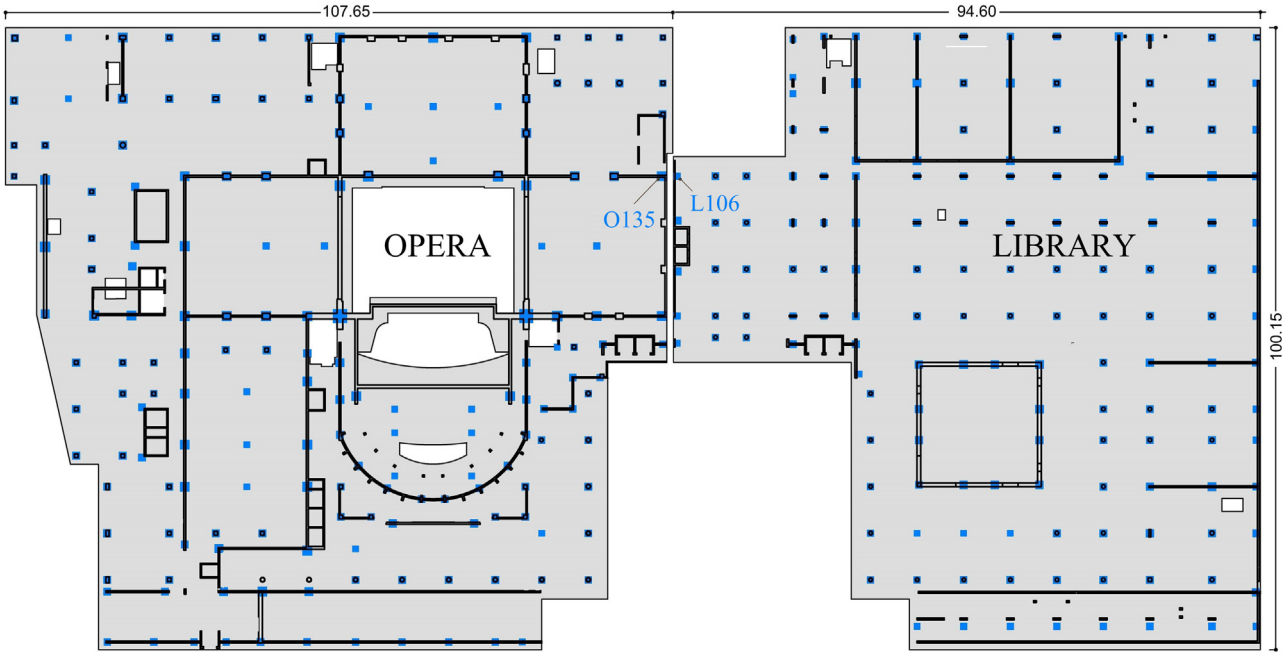

Fig. 2. Plan layout of the ground floor of the Stavros Niarchos Foundation Cultural Center; underneath view with bearings' locations.

2.1. National Opera

The Opera (Fig. 1, Fig. 2) is the largest building on the site with a total area of 28,000 m^2 laid out on eight levels. It is a reinforced concrete (RC) structure, the dominant element of which is a cruciform shape formed by five adjacent cubes of the main and rear stage, side stages and the auditorium. This cruciform forms the heart of the building – both architecturally, where it provides a home for the national opera's activities, and structurally, where the five cubes provide the lateral stability core. This core uses RC walls to provide stiffness in orthogonal directions as well as robust torsional resistance. Additional shear walls throughout the building further increase the overall stiffness. The structure houses the Central Auditorium, the five foyers of the auditorium structured as balconies suspended from the roof, a second smaller stage, and a number of rehearsal rooms, workshops and offices.

The fly tower roof supports the terrace which is accessible to the public and has dimensions of 32.5 m x 22.5 m; the roof slab lies approximately 45 m above the stage pit slab below. Structural walls define the perimeter of the fly tower and substantial openings at the base of these provide links between the main stage and the side stages, rear stage, and auditorium. To prevent buckling under axial loads and resist bending under seismic loads, RC piers provide additional out of plane restraint to the walls. Due to the need to ensure that the isolators lie in the same horizontal plane, as explained in Section 3.4, the stage pit is hung from the adjacent structure, free to move within the surrounding box of diaphragm walls. To create a column-free auditorium, profiled RC ribs cantilever to support the main balconies.

In the foyer, steel balconies span between the external envelope of the auditorium and hangers from the roof above. The roof in this area is clear spanning to a perimeter column line, where high strength steel is used to allow the circular columns to span up to 26 m without intermediate restraint. Cast-in, cruciform head details ensure that any lateral loading is adequately transferred into the inclined, voided roof slab which forms the continuation of the surrounding parkland.

On top of the Opera lies the solar collector roof canopy covering an area of 10,000 m^2. It is a structure made of ferrocement, supported on 30 steel columns that lie on the perimeter of the building. The canopy to column connections use 60 shock absorbers and 120 spring devices to resist the strong wind forces arising and limit the induced movements. The description of this innovative structure is not in the scope of this paper.

The total weight of the Opera, considered for the seismic analysis, is 1150MN of which 890MN are the dead loads and 260MN the live loads (approximately 30% of the dead loads).