European Council of Civil Engineers

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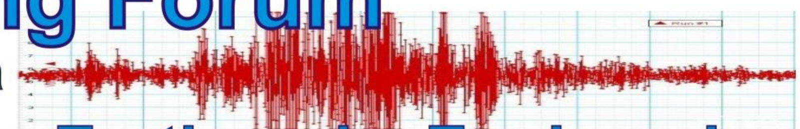
BEF 2021

Building Engineering Forum

20-21 October 2021, Sofia, Bulgaria



International Conference on Earthquake Engineering

The need for Assessment and Seismic Strengthening of Existing Buildings in parallel with Energy Efficiency Improvements – A case study from Cyprus.

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"INTELLIGENT / SMART BUIDINGS"

=

SAFE, SOUND and SUSTAINABLE BUILDINGS

" - The Three S Approach - "

- ECCE moto for 2020 -

1. Summary

- The majority of the existing building stock in many European countries built in the 80s, 70s or earlier lack of modern design standards, including the basic requirements for seismic safety and energy efficiency.
- Thus, based on their date of construction, the vast majority are deficient both in terms of energy and seismic resistance. This creates the need for the society (government, public and engineers) to take actions to keep and maintain the building stock in operational, reliable and resilient state, in order **to ensure primarily the safety of the users.**

- **In addition to safety, nowadays the comfort of the users is of prime importance**. To satisfy the required comfort levels, the user should consume energy, in the form of heating, cooling etc.

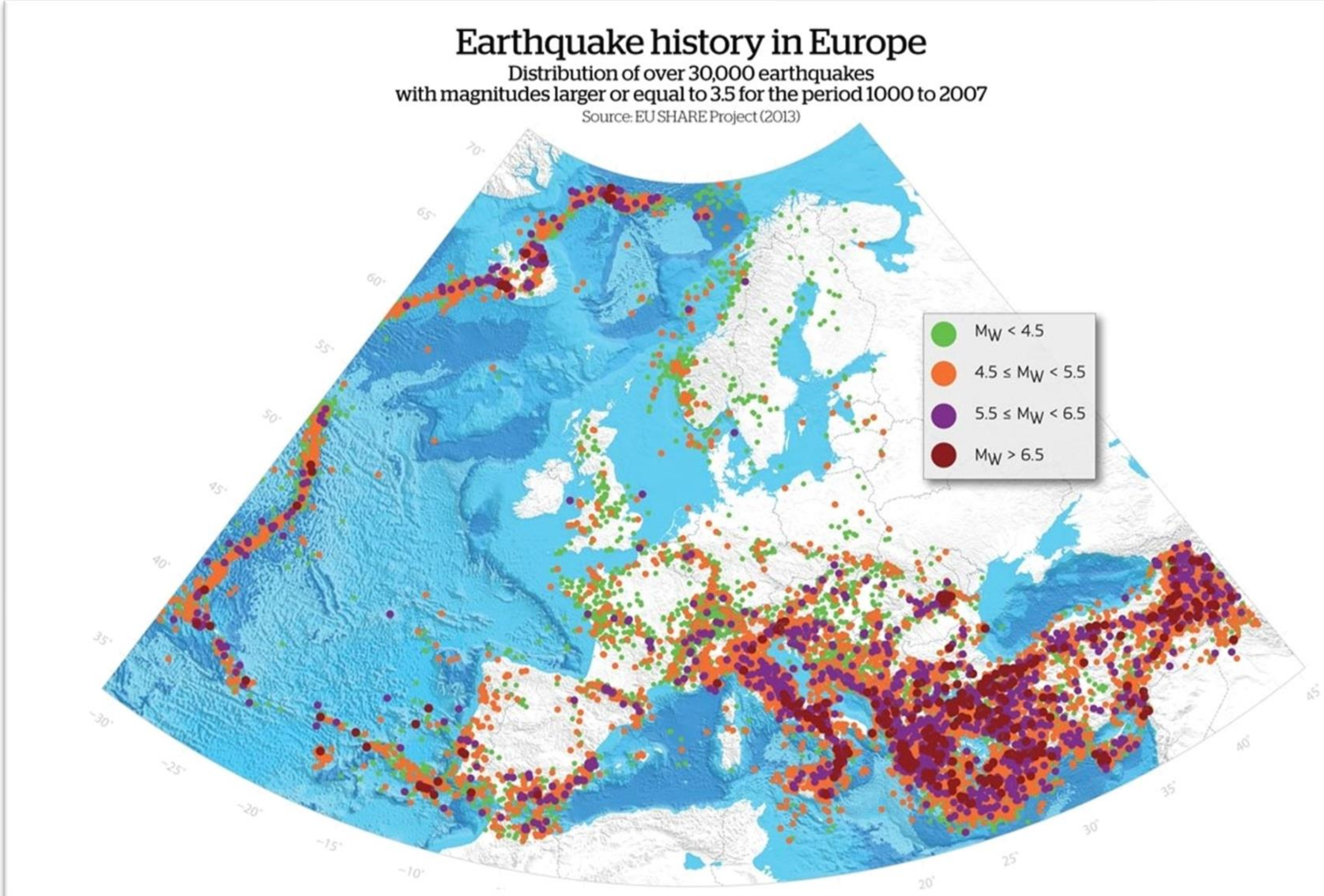
- In civil engineering, this ongoing process is achieved by updating the design codes to incorporate aspects studied after, **extensive research, laboratory work or identified through experience in real hazard situations!.**
- Therefore, this ongoing trend to satisfy those conditions, results in new buildings which are safer, more economic to operate, more secure and more sustainable **(so they satisfy the three S approach).**

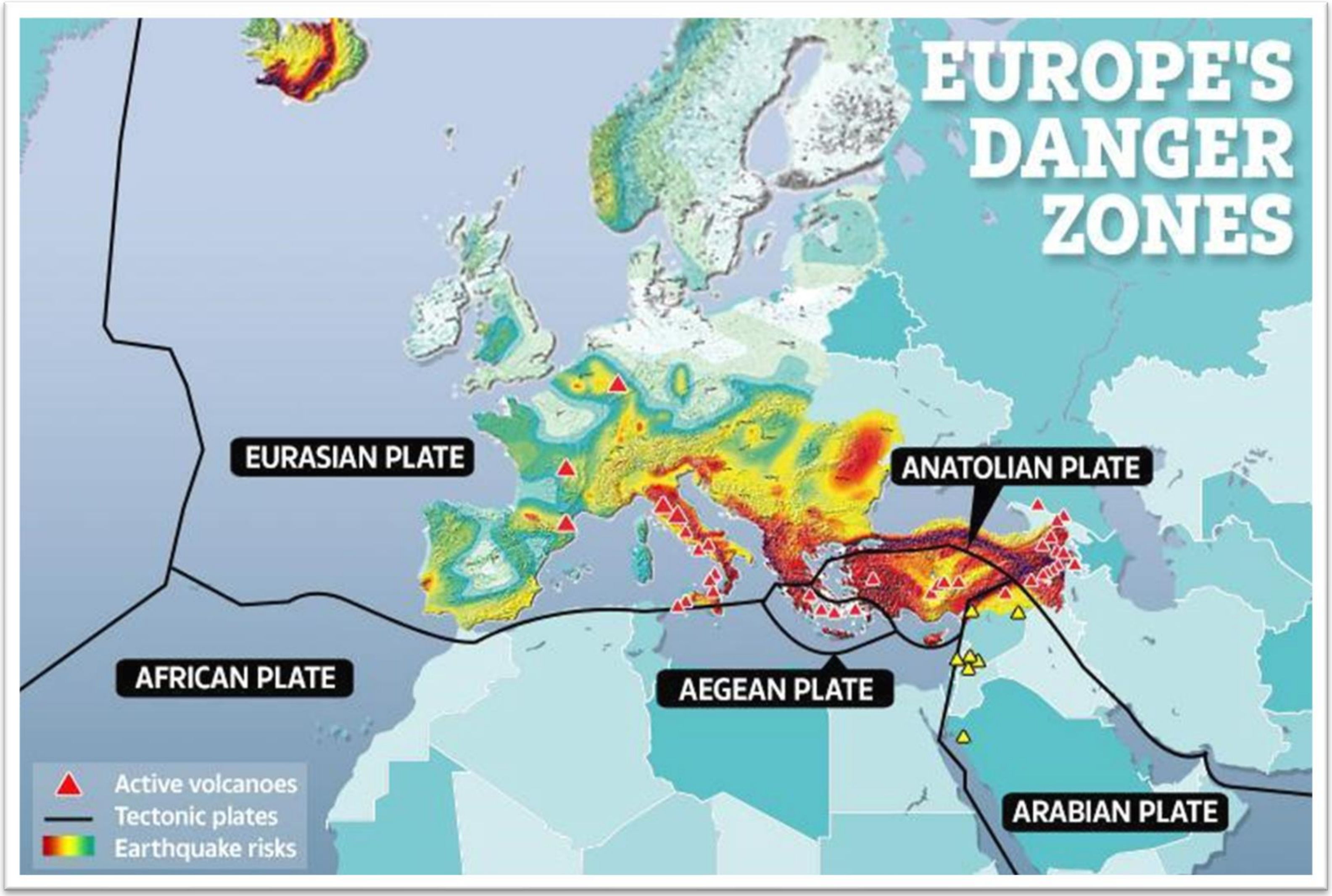
- However, the current building stock of Europe comprises of structures that have been designed and constructed over a long period of years, spanning some decades ago. **For traditional masonry buildings, this can be more than 100+ years.**

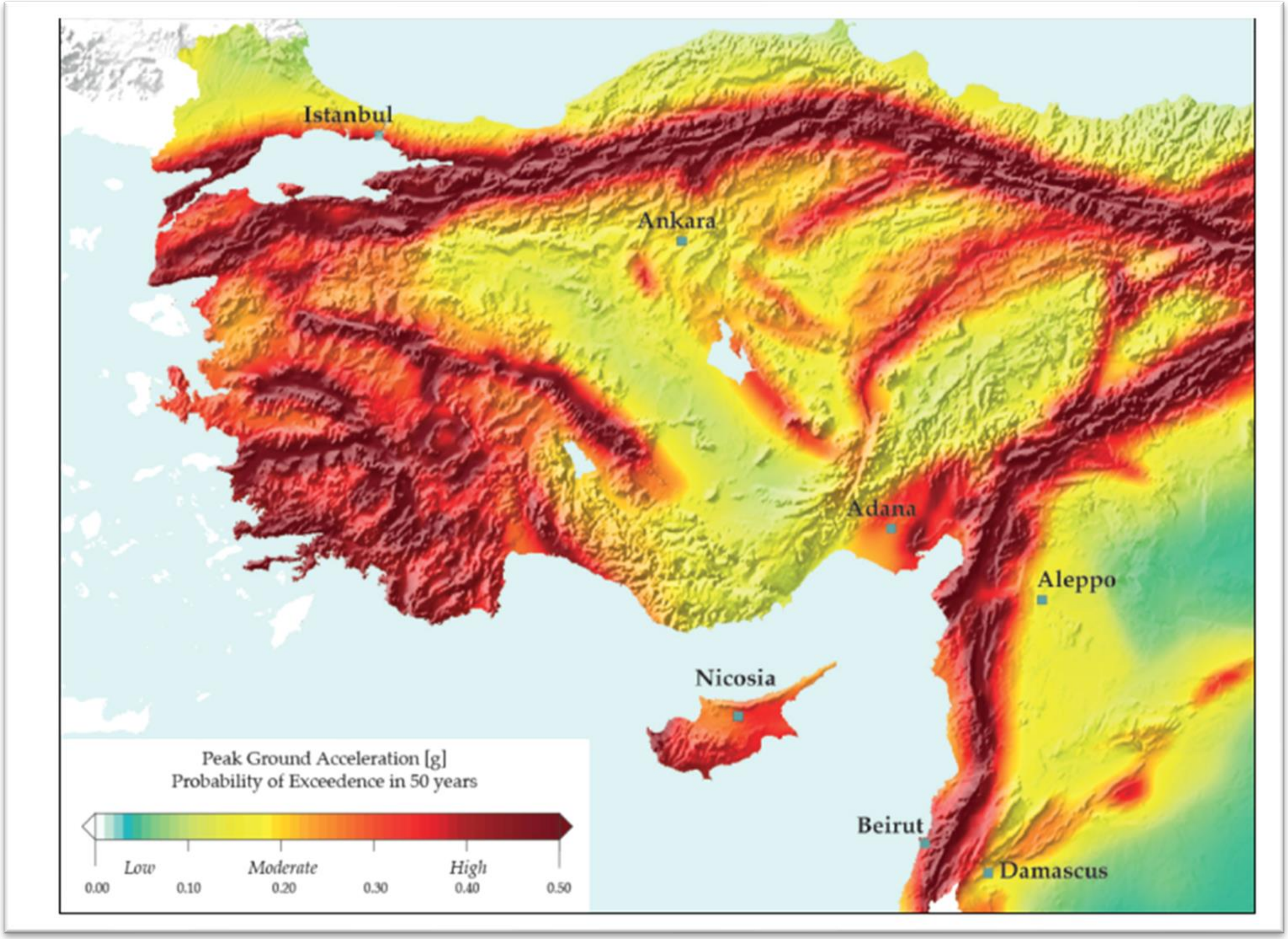
- A BPIE (Buildings Performance Institute Europe) survey [BPIE, 2011] revealed that a significant amount, over 40% of the existing building stock in EU is over 50 years old (only around 17% is constructed after 1991), i.e. exceeding firstly their design life and secondly are constructed during a period that **Seismic knowledge and standards were very limited and energy performance guidelines were non-existent**.

- Thus it is easily understood that for this “aging” group of existing buildings, key challenges lie ahead, regarding their structural safety, sustainability and energy performance.

- The **structural performance of buildings is related to their stiffness and strength as well as their ability to undergo non-linear (ductile) deformations**. The extent to which a building can resist loads depends mainly on the characteristics of its lateral load resisting structure (L.L.R.S., i.e. columns, beams and walls). **Most existing buildings do not pose significant lateral resistance and require upgrading to increase their efficiency and robustness of one or more of the above.**


Earthquake history in Europe
Distribution of over 30,000 earthquakes
with magnitudes larger or equal to 3.5 for the period 1000 to 2007
Source: EU SHARE Project (2013)
$M_W < 4.5$
$4.5 \le M_W < 5.5$
$5.5 \le M_W < 6.5$
$M_W > 6.5$
70°
65°
60°
55°
50°
45°
40°
35°
-30°
-25°
-20°
-15°
-10°
20°
25°
30°
35°
40°
45°


EUROPE'S DANGER ZONES
EURASIAN PLATE
ANATOLIAN PLATE
AFRICAN PLATE
AEGEAN PLATE
ARABIAN PLATE
Active volcanoes
Tectonic plates
Earthquake risks


Istanbul
Ankara
Adana
Aleppo
Nicosia
Beirut
Damascus
Peak Ground Acceleration [g]
Probability of Exceedence in 50 years
Low
Moderate
High
0.00
0.10
0.20
0.30
0.40
0.50

- In the case of the aging existing buildings, the lack of consideration at the design and construction stage for the seismic effect, means this building stock **is more vulnerable to earthquakes**. In addition, as it is exceeding its design life of 50 years, it means that along with strengthening interventions to improve the seismic performance, **durability and structural assessments** should also be carried-out to ensure functionality and thus safety and comfort for the users.
- In addition to safety, in the last decade the importance on the energy front has been hugely highlighted. Increased energy consumption lead to adverse environmental impact (e.g. climate change). Therefore, for the building sector the energy efficiency term is introduced, which was highlighted by the Europe's aim to reduce by 2020 the Greenhouse emissions by 20% and achieve 20% energy savings [EPBD recast, 2010/31/EU].
- **It is evident that** there is a big portion of the existing EU building block that is under-designed, both regarding their seismic capacity and also their energy performance, and **therefore in need of structural and energy renovation to remain operational and safe.**

- To improve the seismic performance/capacity of existing buildings that have not been designed according to the earthquake standards of Eurocode EC8, a variety of techniques based on the typology of the building and the level of the required strengthening are currently used.
- For RC structures, the seismic retrofit techniques are generally divided to local and global methods [JRC 2014a]:

Local methods are concentrated in improving the performance of particular structural members and most commonly include the strengthening of the column-to-beam joints, column and beam jacketing and column and beam strengthening with advance materials such as fibre reinforced polymers (FRP) or combined with new technology such as the textile reinforced mortar (TRM) technique, or with traditional R.C. jacketing.

Global methods may be provided with the addition of shear walls and/ or foundations strengthening, which will lead t**o the change of the type of the structural system**.

- Regarding the energy performance level of buildings, it is influenced by a number of factors including the installed heating/cooling systems, the climatic conditions and the building envelope. The energy demand of buildings can be reduced **by improving the insulation of the envelope, increasing the thermal capacity of the building and by using energy efficient systems in the building's operating processes.**

- The insulation of the envelope can be drastically improved by reducing the energy loss from windows and doors and by insulating the walls and the roof. The level of improvement depends on the thickness of the provided insulation and the properties of the insulating material, although thick insulating layers are sometimes unfavorable due to limitations in space, aesthetics reasons and other technical constraints [JRC 2014a].

- Currently, from a sustainability perspective, emphasis must be placed on developing an integrated structural and energy design methodology for new buildings that should be preferred over individual actions, to ensure a **Sustainable Structural Design (SSD).** Such approaches like the SSD methodology **will ensure that new buildings satisfy both structural safety and energy efficiency targets.**

- However, for existing buildings, especially of a certain construction age, **the problem of seismic and energy inefficiency is of primary importance and a similar in concept approach is required to provide upgrading on both fronts.**

Given that buildings in some European regions experience frequent seismic activity and high temperature variations, **it becomes a necessity to proceed with upgrading or retrofitting measures as part of a major refurbishment process.**

These measures are expected to improve the resilience of the existing building stock in an economically feasible way, reduce the operational expenses, contribute to the sustainability of the society and the environment and offer safer buildings to people (**Home**).

As it is well known to all Engineers if buildings are cladded and insulated, **then they may look new, but their underlying structural issues remain, hidden, unseen and unassessed and may become life-threatening, especially in case of a major seismic event and may lead to a collapse or failure.**

If that occurs, then all EU money spent for energy Upgrades and refurbishment of buildings would be lost.

However, the economic risk is redundant compared to the potential injury and loss of Human Life.

2.0 Another new trend is … *smart financing for smart buildings.*

But, a building can only be called smart once it is safe, sound and sustainable.

The starting point for **every Country in Europe** must be ***all state/government buildings and all buildings of high importance,***

as categorized in the Eurocodes, as well as **private buildings** that concentrate a lot of people.

3. Scope

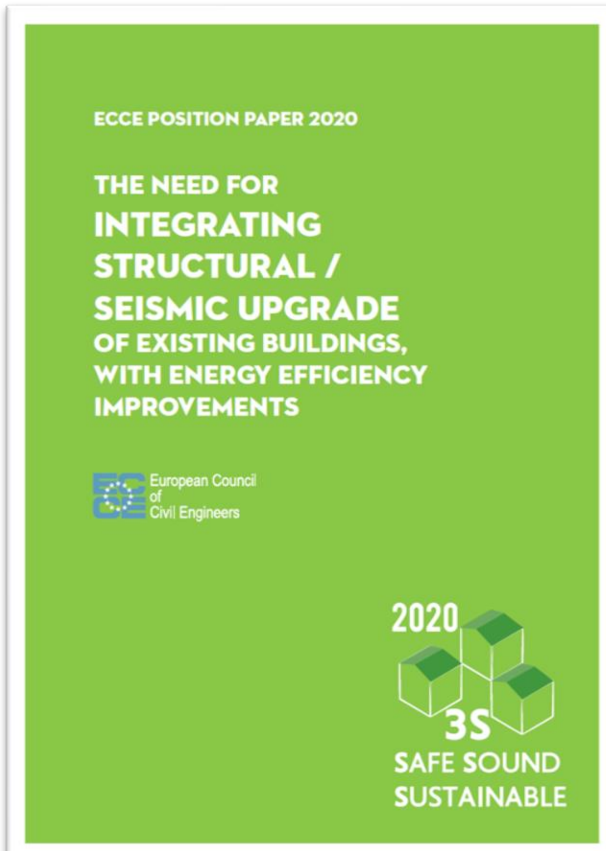
- Our aim through the production of the position paper was to ensure sustainability, resilience and safety of existing buildings through structural or seismic upgrading, against seismic and other dynamic actions and also enhanced energy efficiency.

- The solution provided should **follow a holistic approach to address the issues simultaneously** and link individual retrofit/upgrading activities in an integrated procedure. One of the most important issues, which defines the way of living, **is safe, sound, and sustainable buildings (the three S approach), …. And that is a basic Human right.**

- **That is why we decided as ECCE in 2019 to create a Position Paper**, in order to convince E.U. member states and Brussels **to grant funding for the Assessment and Structural and / or Seismic Upgrade of Buildings, t**ogether with the grants given for the improvement of the energy performance of buildings, under Directive 2010/31/EM, of the European Parliament and of the Council of 19th of May 2010.

4. POSITION PAPER

The position paper was finally created and distributed in 2020. It can be found at : http://www.ecceengineers.eu/position_papers/index.php



5. The working team

The Basic Team was:

a)	Eur. Ing. Platonas Stylianou	Cyprus (P.S.), Basic Author and Coordinator of the working team,
b)	Mr. Aris Chatzidakis	Greece, (A.C.)
c)	Mr. Andreas Theodotou	Cyprus, (A.T.)
d)	Dr. Nicolas Kyriakides	Cyprus, (N.K.)
e)	Mr. Andreas Brandner	Austria, (A.B.)
f)	Dr. Branko Zadnik	Slovenia, (B.Z.)
g)	Mr. Ivan Paska	Croatia (I.P.)
h)	Mr. Paul Coughlan	United Kingdom, (P.C.)

6. The content

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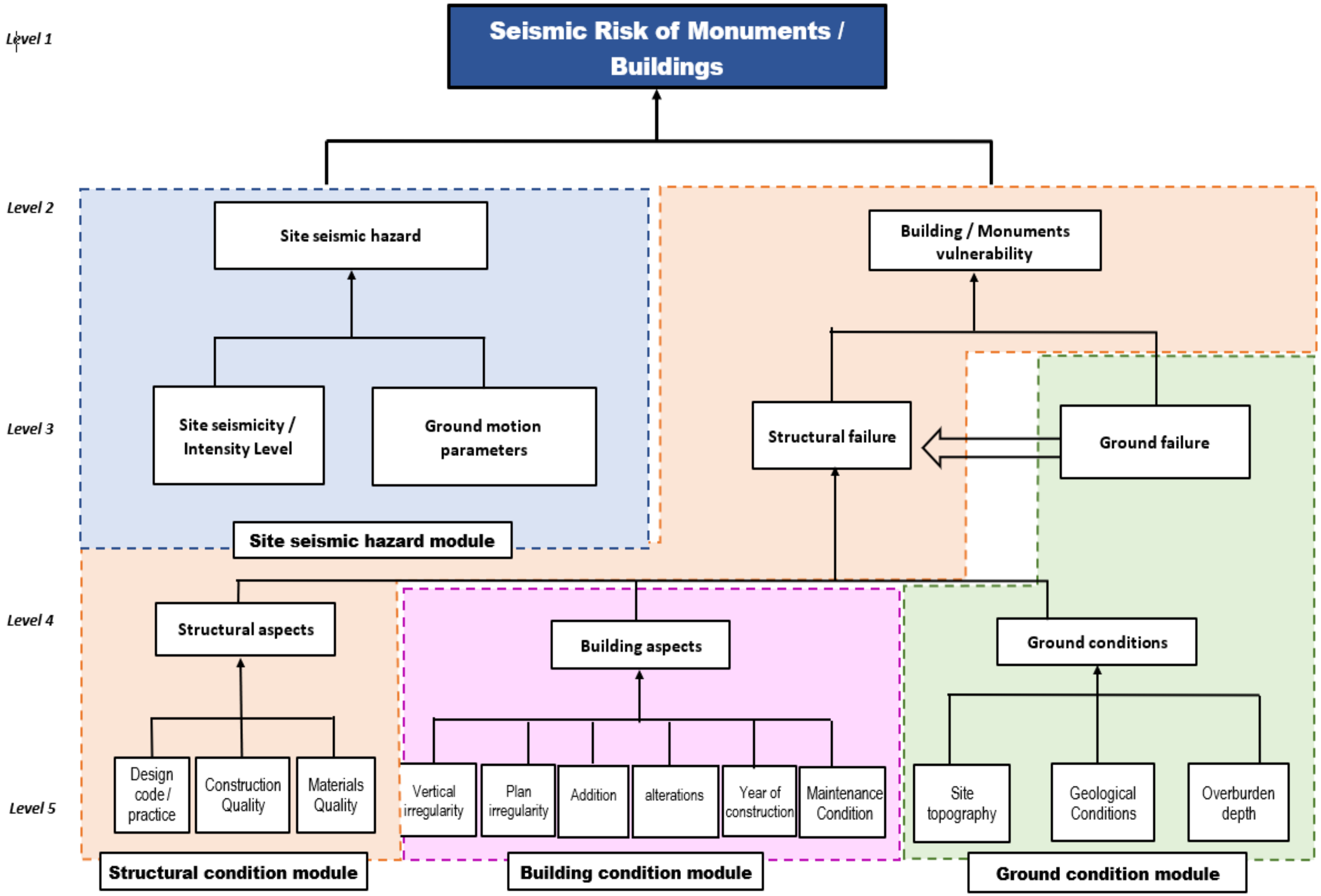
7. Seismic Risk Chart

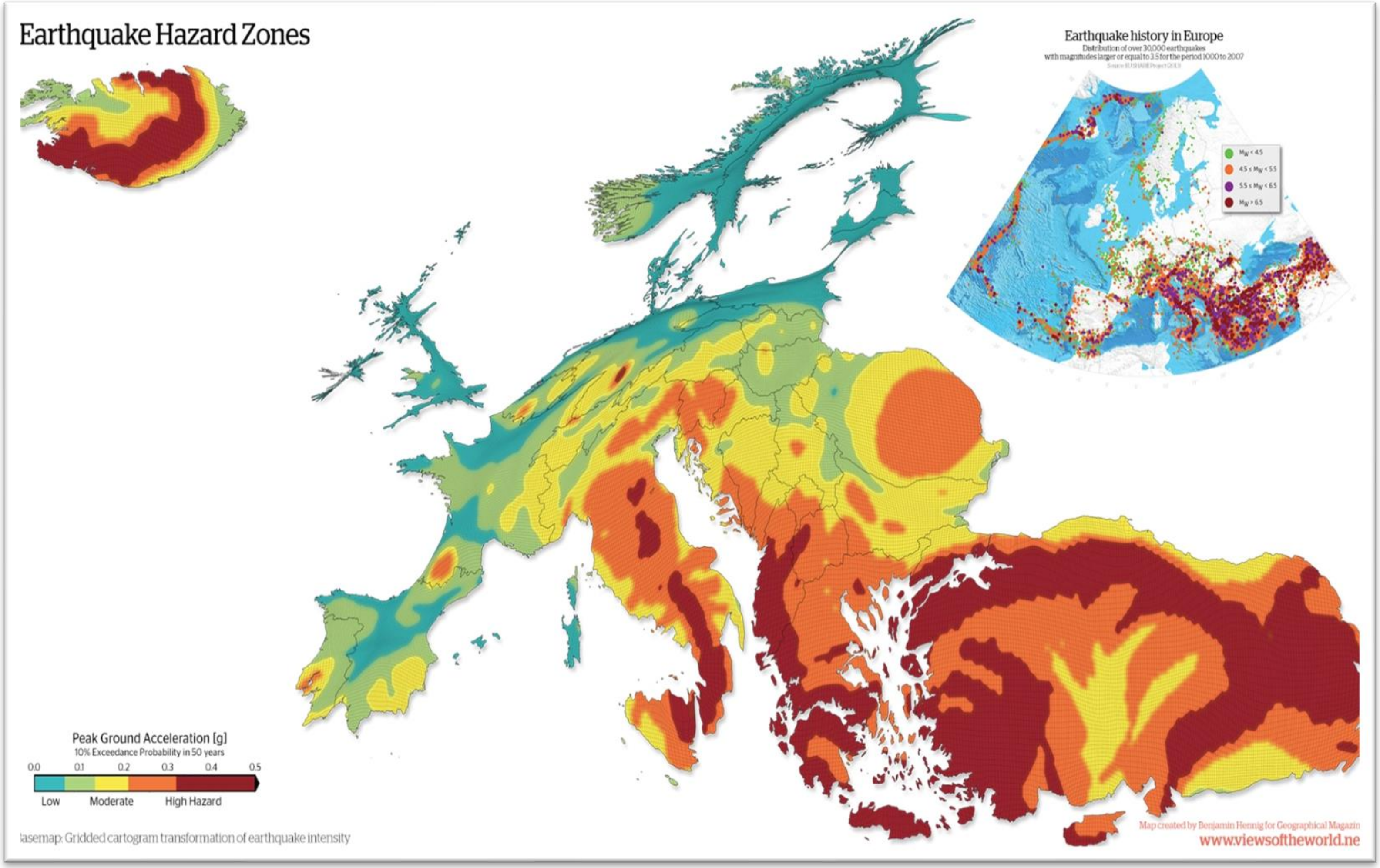


8. Expected Benefit

1. Raise awareness and demand for better and structurally sound buildings among stakeholders, governments, owners, operators and all citizens.
2. Improve knowledge and information regarding assessment and design for structural and/or seismic upgrading of existing buildings.
3. Increase funding opportunities from EU.
4. Offer a significant contribution to the community, as the need to protect the homes and build property, is a basic one, that originates from antiquity.

By applying the idea expressed in the position paper, countries that possess abandoned, deteriorated or ill-maintained buildings, **especially those subject to seismic hazard, can assess, evaluate and if necessary, structurally strengthen their buildings,** in order to obtain the same or better structural capacity than what was mandated by the building codes and allowed by the construction practices at the time of the original construction.

9. The biggest Earthquakes in Europe the last 10-15 years.



Izmit Earthquake (Turkey)-17 August 1999

- On 17 of August, 1999 at 03:01:3 (Local Time) there was a strong earthquake, M = 7.4 on the Richter Scale, with its epicentre South-West of Izmit town in northern Turkey and at a depth of 15-17Km.
- The duration of seismic vibration was 37 sec. The earthquake shook the cities of the wider area such as Istanbul, Bursa, Eskishir, Duze and Bolu.
- The impact was dramatic, 17,118 civilians died, 45,000 injured, 600,000 homeless and thousands were missing.
- The financial impact of the devastating earthquake amounts to **appr 50 billion**. dollars without taking into account all the long-term impact.

Earthquake in the city of Duzce, Turkey 12/11/1999

- On November 12, 1999 at 18:57:22 (local time) a strong earthquake of magnitude, **Mw = 7.2. Acceleration reached PGA = 1g,** as it was recorded by the accelerator in the city of Duzce.
- The deaths caused by the earthquake reached 1,000 and more than 5,000 people were injured, 55,000 were forced to leave their homes.
- The economical impact **has exceeded $ 1 billion.**

<u>Earthquake in the city of Laquila (Italy)</u>

- On April 6, 2009, a strong earthquake excitation Mw = 6.3 or 5.9 magnitude on the Richter Scale, occurred with its epicentre 7km outside of the city of L'Aquila at a depth of 10km deep.
- The earthquake was fatal and 319 people were killed, 1,600 were injured and more than 10,000 homes were damaged, 70,000 were forced to leave their homes, where 30,000 were left homeless for several months.
- The economical impact of the earthquake exceeded $ 15 billion and created a major unemployment problem. **<u>But the cultural impact was also great due to of the damage or collapse of several buildings of the Medieval Period.</u>**

<u>Earthquake of Parnitha (Athens) 1999</u>

- On September 7, 1999, there was a strong earthquake excitation, M = 5.9 on the Richter Scale with its epicentre, 18km north of downtown Athens.
- The horizontal acceleration exceeded 0.5g in central Athens while the vertical reached 1 g.
- The impacts of the earthquake were dramatic, **145 people lost their lives, 2,000 were injured and 50,000 were left homeless.**
- The financial impact reached <u>$ 4 billion, with 110 buildings collapsing completely and more than 50,000</u> buildings were damaged.

Earthquake of Central Italy - 2016

- On August 24, 2016 there was a strong earthquake excitation, M = 6,2 on the Richter Scale with its epicentre, Southeast of Norcia, the focal depth of the earthquake was 10km.
- The impacts of the earthquake were dramatic, 299 people lost their live, more than 400 were injured and 4.500 were left homeless.
- The financial impact was **appr $ 11 billion.**
- **The cultural impact was dramatic.**

Earthquake of Samos & Izmir

- On October 30, 2020, an earthquake of a 7.0 Mw (UGGS) magnitude occurred Northeast of the Greek island of Samos.
- Many buildings severely damaged in Samos, Greece and Izmir, Turkey.
- A small-scale tsunami followed the earthquake.
- **119 people died, at least 15,000 homeless.**
- Preliminary Estimated damage > $600 million.

Crete Earthquake

- On September 30, 2021, a 6.0 Mw (EMSC) magnitude earthquake struck the island of Crete in Greece.
- The epicenter was located at the mainland of the island of Crete, at a depth of 8.7 km.
- **The peak ground acceleration recorded, was 0.82g (vertical) in Arkalochori.**
- 1 person killed, 36 injured.
- More than 10 aftershocks > 4.0 Mw followed the main event.

<u>**Petrinja Earthquake (Croatia)**</u>

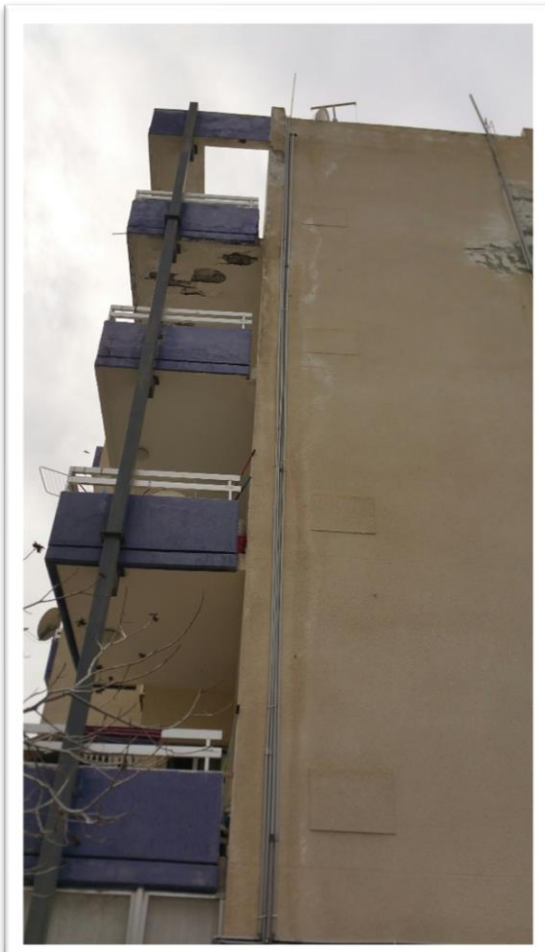
- On December 29, 2020, a 6.4 Mw magnitude earthquake hit Central Croatia.
- Depth: 10 km
- Duration: 26 seconds
- **7 people died.**
- Many buildings collapsed in Petrinja, Croatia.
- The total damage is estimated at <u>**appr. 5 – 5.5 billion euros.**</u>

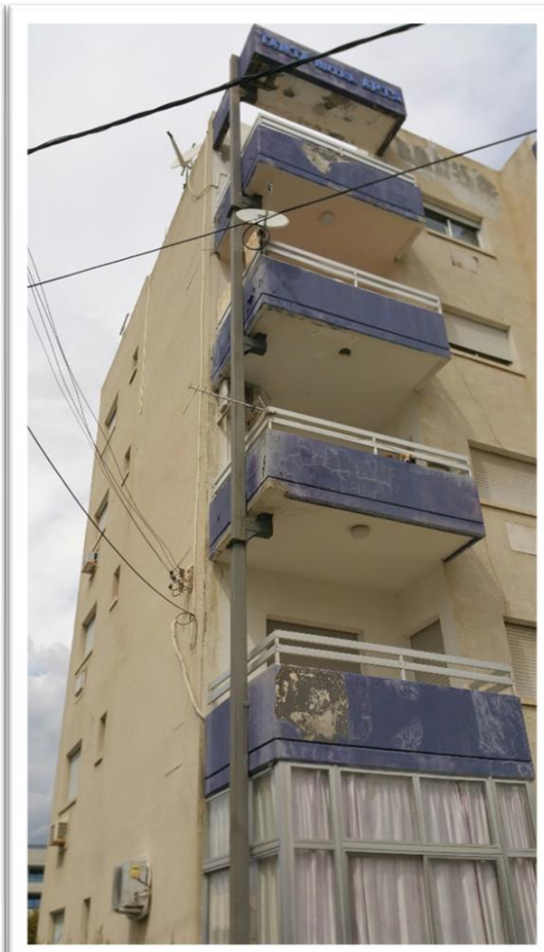
10. Example of Seismic/Structural Update of a Building (Cyprus).

- The building is situated in Germasogeia Limassol, Cyprus.
- Building was constructed circa 1980.
- The existing building consisted of ground floor (used as utility area) and five more floors above and was serving as a small business hotel.

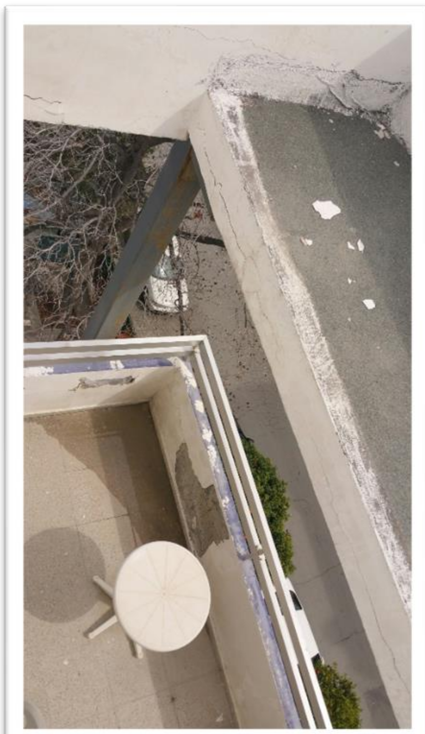
Building under assessment

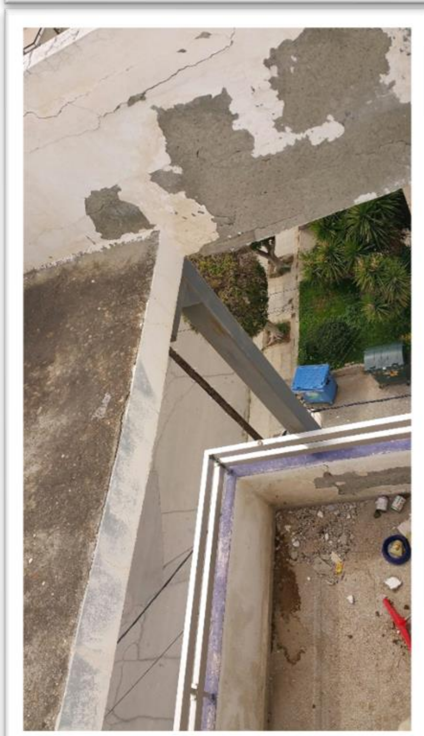
- The situation of the building before strengthening.





More photos





- 3D Drawings of the proposed renovated building, energy upgraded and with the addition of an extra floor.

10.1 In situ Testing and Site Inspection Results.

Extensive in-situ testing has been carried out by an authorized laboratory during the field survey. Testing scope included the collection of cylindrical samples from structural elements that their properties were going to be determined later in the lab by destructive methods. Also to identify and record the reinforcement geometry and properties in various selected locations.

Κωδικός Δοκιμίου	Ποσοστό Πόρων	Κωδικός Δοκιμίου	Ποσοστό Πόρων
Κ1 Ισογείου	Μεγάλοι Excess Voidage 0.0%	Δ1 2ου Ορόφου	Μικροί Excess Voidage 0.0%
Κ2 Ισογείου	Μεγάλοι Παρουσία κυψελίδων Excess Voidage 10.0%	Δ2 2ου Ορόφου	Μικροί Excess Voidage 0.0%
Κ3 Ισογείου	Μικροί, Μέτριοι, Μεγάλοι Παρουσία κυψελίδων Excess Voidage 4.0%	Δ3 2ου Ορόφου	Παρουσία κυψελίδων Excess Voidage 1.0%
Δ1 Ισογείου	Μέτριοι, Μεγάλοι Excess Voidage 0.5%	Κ1 3ου Ορόφου	Μικροί, Μέτριοι, Μεγάλοι Excess Voidage 1.5%
Δ2 Ισογείου	Excess Voidage 0.0%	Κ2 3ου Ορόφου	Μικροί, Μέτριοι Excess Voidage 0.5%
Δ3 Ισογείου	Μικροί, Μέτριοι Excess Voidage 1.5%	Κ3 3ου Ορόφου	Μικροί, Μέτριοι Excess Voidage 0.5%
Κ1 1ου Ορόφου	Μέτριοι, Μεγάλοι Παρουσία κυψελίδων Excess Voidage 2.0%	Κ4 3ου Ορόφου	Μικροί, Μέτριοι, Μεγάλοι Παρουσία κυψελίδων Excess Voidage 1.5%
Κ2 1ου Ορόφου	Μέτριοι, Μεγάλοι Παρουσία κυψελίδων Excess Voidage 1.0%	Δ1 3ου Ορόφου	Μεγάλοι Παρουσία κυψελίδων Excess Voidage 1.5%
Κ3 1ου Ορόφου	Μέτριοι, Μεγάλοι Excess Voidage 1.0%	Δ2 3ου Ορόφου	Μέτριοι, Παρουσία κυψελίδων Excess Voidage 1.0%
Δ1 1ου Ορόφου	Excess Voidage 0.0%	Δ3 3ου Ορόφου	Μικροί Excess Voidage 0.0%
Δ2 1ου Ορόφου	Παρουσία κυψελίδων Excess Voidage 0.0%	Δ4 3ου Ορόφου	Μικροί, Μέτριοι Excess Voidage 0.5%
Δ3 1ου Ορόφου	Μικροί Excess Voidage 0.0%	Κ1 4ου Ορόφου	Μικροί Excess Voidage 0.0%
Κ1 2ου Ορόφου	Παρουσία κυψελίδων Excess Voidage 1.5%	Κ2 4ου Ορόφου	Μέτριοι, Μεγάλοι Excess Voidage 0.0%
Κ2 2ου Ορόφου	Μικροί, Μέτριοι Παρουσία κυψελίδων Excess Voidage 1.0%	Δ1 4ου Ορόφου	Παρουσία κυψελίδων Excess Voidage 1.0%
Κ3 2ου Ορόφου	Μεγάλοι Excess Voidage 0.0%	Δ2 4ου Ορόφου	Παρουσία κυψελίδων Excess Voidage 5.0%

Τα αναλυτικά αποτελέσματα της θλιπτικής αντοχής παρουσιάζονται στο Παράρτημα Α συνοδευόμενα από τα σχέδια των σημείων εξαγωγής των δοκιμίων. Οι αντοχές που αναφέρονται στην τελευταία στήλη του πίνακα αποτελεσμάτων της θλιπτικής αντοχής αντιπροσωπεύουν την αντοχή κύβου που καθορίσθηκε με τη σχετική μετατροπή της αντοχής κυλινδρικού δοκιμίου με βάση το πρότυπο BS1881-120.

Κωδικός Δοκιμίου	Επί τόπου θλιπτική αντοχή (κύβου)	Αξιολόγηση σύμφωνα με το πρότυπο CYS EN 13791 §9
Κ1 Ισογείου	23.8	Ικανοποιητική**
Κ2 Ισογείου	14.7	Μη ικανοποιητική**
Κ3 Ισογείου	15.7	Μη ικανοποιητική**
Μέσος όρος	18.1	$f_{m(n),is}$
Τυπική Απόκλιση	5.0	
Επί τόπου εκτιμημένη χαρακτηριστική αντοχή*	11.1	$f_{m(n),is}$ – k, where k is 7
Δ1 Ισογείου	13.5	Μη ικανοποιητική**
Δ2 Ισογείου	18.5	Ικανοποιητική**
Δ3 Ισογείου	10.2	Μη ικανοποιητική**
Μέσος όρος	14.1	$f_{m(n),is}$
Τυπική Απόκλιση	4.2	
Επί τόπου εκτιμημένη χαρακτηριστική αντοχή*	7.1	$f_{m(n),is}$ – k, where k is 7
Κ1 1ου Ορόφου	35.8	Ικανοποιητική**
Κ2 1ου Ορόφου	22.3	Ικανοποιητική**
Κ3 1ου Ορόφου	30.0	Ικανοποιητική**
Μέσος όρος	29.4	$f_{m(n),is}$
Τυπική Απόκλιση	6.8	
Επί τόπου εκτιμημένη χαρακτηριστική αντοχή*	22.4	$f_{m(n),is}$ – k, where k is 7
Δ1 1ου Ορόφου	19.1	Ικανοποιητική**
Δ2 1ου Ορόφου	21.8	Ικανοποιητική**
Δ3 1ου Ορόφου	14.0	Ικανοποιητική**
Μέσος όρος	18.3	$f_{m(n),is}$
Τυπική Απόκλιση	4.0	
Επί τόπου εκτιμημένη χαρακτηριστική αντοχή*	11.3	$f_{m(n),is}$ – k, where k is 7

Κωδικός Δοκιμίου	Επί τόπου θλιπτική αντοχή (κύβου)	Αξιολόγηση σύμφωνα με το πρότυπο CYS EN 13791 §9
Κ1 2ου Ορόφου	30.9	Ικανοποιητική**
Κ2 2ου Ορόφου	20.3	Ικανοποιητική**
Κ3 2ου Ορόφου	23.4	Ικανοποιητική**
Μέσος όρος	24.9	$f_{m(n),is}$
Τυπική Απόκλιση	5.5	
Επί τόπου εκτιμημένη χαρακτηριστική αντοχή*	17.9	$f_{m(n),is}$ – k, where k is 7
Δ1 2ου Ορόφου	13.7	Ικανοποιητική**
Δ2 2ου Ορόφου	22.3	Ικανοποιητική**
Δ3 2ου Ορόφου	12.2	Μη ικανοποιητική**
Μέσος όρος	16.1	$f_{m(n),is}$
Τυπική Απόκλιση	5.5	
Επί τόπου εκτιμημένη χαρακτηριστική αντοχή*	9.1	$f_{m(n),is}$ – k, where k is 7
Κ1 3ου Ορόφου	40.3	Ικανοποιητική**
Κ2 3ου Ορόφου	23.9	Ικανοποιητική**
Κ3 3ου Ορόφου	33.5	Ικανοποιητική**
Κ3 3ου Ορόφου	23.2	Ικανοποιητική**
Μέσος όρος	30.2	$f_{m(n),is}$
Τυπική Απόκλιση	8.2	
Επί τόπου εκτιμημένη χαρακτηριστική αντοχή*	23.2	$f_{m(n),is}$ – k, where k is 7
Δ1 3ου Ορόφου	11.1	Μη ικανοποιητική**
Δ2 3ου Ορόφου	17.8	Ικανοποιητική**
Δ3 3ου Ορόφου	13.2	Μη ικανοποιητική**
Δ4 3ου Ορόφου	13.2	Μη ικανοποιητική**
Μέσος όρος	13.8	$f_{m(n),is}$
Τυπική Απόκλιση	2.8	
Επί τόπου εκτιμημένη χαρακτηριστική αντοχή*	6.8	$f_{m(n),is}$ – k, where k is 7

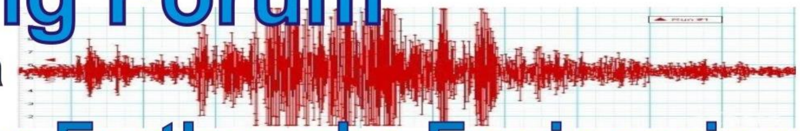
*Ο υπολογισμός της επί τόπου εκτιμημένης χαρακτηριστικής αντοχής έγινε σύμφωνα με την παράγραφο 7.3.3 του προτύπου CYS EN 13791.

Η αξιολόγηση έγινε σύμφωνα με το πρότυπο CYS EN 13791 §9 και με τη υπόθεση ότι για την κατασκευή των κολώνων χρησιμοποιήθηκε σκυρόδεμα κατηγορίας C20/25** (ικανοποιητικό αποτέλεσμα **>17.85N/mm²** = (25-4)*0.85 και για την κατασκευή των δοκών σκυρόδεμα κατηγορίας C15/**20** (ικανοποιητικό αποτέλεσμα **>13.6N/mm²** = (20-4)*0.85).

Κωδικός Δοκιμίου	Επί τόπου θλιπτική αντοχή (κύβου)	Αξιολόγηση σύμφωνα με το πρότυπο CYS EN 13791 §9
Κ1 4ου Ορόφου	6.0	Μη ικανοποιητική**
Κ2 4ου Ορόφου	15.0	Μη ικανοποιητική**
Μέσος όρος	10.5	$f_{m(n),is}$
Δ1 4ου Ορόφου	23.8	Ικανοποιητική**
Δ2 4ου Ορόφου	13.1	Μη ικανοποιητική**
Μέσος όρος	18.4	$f_{m(n),is}$

**Ο υπολογισμός της επί τόπου εκτιμημένης χαρακτηριστικής αντοχής έγινε σύμφωνα με την παράγραφο 7.3.3 του προτύπου CYS EN 13791.

Η αξιολόγηση έγινε σύμφωνα με το πρότυπο CYS EN 13791 §9 και με τη υπόθεση ότι για την κατασκευή των κολώνων χρησιμοποιήθηκε σκυρόδεμα κατηγορίας C20/25** (ικανοποιητικό αποτέλεσμα **>17.85N/mm²** = (25-4)*0.85 και για την κατασκευή των δοκών σκυρόδεμα κατηγορίας C15/**20** (ικανοποιητικό αποτέλεσμα **>13.6N/mm²** = (20-4)*0.85).



Από τον έλεγχο που έγινε, η ενανθράκωση στα είκοσι οκτώ από τα τριάντα δοκίμια που έχουν εξαχθεί έχει προχωρήσει πέραν του πάχους της επικάλυψης του οπλισμού (cover) που υπολογίζεται να είναι της τάξης των 2.0cm. Σε γενικές γραμμές η ενανθράκωση κυμαίνεται από 0.0 μέχρι 9.0cm.

Κωδικός Δοκιμίου	Ενανθράκωση cm	Κωδικός Δοκιμίου	Ενανθράκωση cm
Κ1 Ισογείου	4.0 – 4.5	Δ1 2ου Ορόφου	5.0 – 5.5
Κ2 Ισογείου	4.5 – 5.0	Δ2 2ου Ορόφου	4.0 – 4.5
Κ3 Ισογείου	4.5 – 5.0	Δ3 2ου Ορόφου	5.5 – 6.0
Δ1 Ισογείου	4.0 – 4.5	Κ1 3ου Ορόφου	0.0
Δ2 Ισογείου	4.5 – 5.0	Κ2 3ου Ορόφου	2.5 – 3.0
Δ3 Ισογείου	8.0 – 8.5	Κ3 3ου Ορόφου	2.5 – 3.0
Κ1 1ου Ορόφου	2.0 – 2.5	Κ4 3ου Ορόφου	3.0 – 3.5
Κ2 1ου Ορόφου	5.5 – 6.0	Δ1 3ου Ορόφου	8.5 – 9.0
Κ3 1ου Ορόφου	2.5 – 3.0	Δ2 3ου Ορόφου	5.5 – 6.0
Δ1 1ου Ορόφου	5.0 – 5.5	Δ3 3ου Ορόφου	8.0 – 8.5
Δ2 1ου Ορόφου	4.5 – 5.0	Δ4 3ου Ορόφου	5.0 – 5.5
Δ3 1ου Ορόφου	5.5 – 6.0	Κ1 4ου Ορόφου	0.0
Κ1 2ου Ορόφου	2.0 – 2.5	Κ2 4ου Ορόφου	4.5 – 5.0
Κ2 2ου Ορόφου	3.5 – 4.0	Δ1 4ου Ορόφου	4.0 – 4.5
Κ3 2ου Ορόφου	4.0 – 4.5	Δ2 4ου Ορόφου	4.0 – 4.5

Βαθμός Αλκαλικότητας

Στη χώρα μας είναι εξαιρετικά σπάνιο το ενδεχόμενο σταδιακής αποσύνθεσης του σκυροδέματος λόγω εναλλαγών πήξεως-τήξεως του νερού των πόρων ή λόγω αλκαλοπυριτικής αντίδρασης. Συνεπώς το κύριο πρόβλημα από άποψη ανθεκτικότητας του οπλισμένου σκυροδέματος είναι η διάβρωση των οπλισμών. Οι ράβδοι οπλισμού προστατεύονται από τη διάβρωση μέσω ενός πολύ λεπτού επιφανειακού στρώματος ένυδρου οξειδίου του σιδήρου, που δημιουργείται λόγω της υψηλής αλκαλικότητας του σκυροδέματος που τις περιβάλλει. Το σκληρυμένο σκυρόδεμα περιέχει μεγάλο ποσοστό οξειδίου του ασβεστίου, $Ca(OH)_2$, στο νερό των πόρων έτσι ώστε να δημιουργείται αλκαλικό περιβάλλον με τιμή pH γύρω στο 12.5. Με αυτόν τον τρόπο προστατεύεται ο χάλυβας από τη διάβρωση εφόσον το οξείδιο παραμένει ανέπαφο. Αυτό το φαινόμενο είναι γνωστό ως παθητικοποίηση του χάλυβα. Οι τρεις βασικοί λόγοι διάβρωσης του χάλυβα είναι η ενανθράκωση του σκυροδέματος, η επίδραση των χλωριόντων και οι ρωγμές που δημιουργούνται είτε λόγω παρουσίας θειικών αλάτων είτε λόγω καθιζήσεων.

Από τα αποτελέσματα φαίνεται ότι η αλκαλικότητα στο επιφανειακό σκυρόδεμα, την περιοχή που έχει επηρεαστεί περισσότερο από την ενανθράκωση, έχει μειωθεί σε μεγάλο βαθμό και κυμαίνεται από 8.6 μέχρι 12.1. Στις περιοχές που το σκυρόδεμα δεν έχει επηρεαστεί σε σημαντικό βαθμό από την ενανθράκωση, η αλκαλικότητα βρίσκεται σε ψηλότερα επίπεδα. Ο έλεγχος της αλκαλικότητας έγινε σε δυο τμήματα για το κάθε κυλινδρικό δοκίμιο. Το τμήμα στο οποίο έχει επηρεαστεί από την ενανθράκωση και στο τμήμα που πιθανόν να μην έχει επηρεαστεί.

Κωδικός Δοκιμίου	Περιοχή Ελέγχου (cm)	pH	Κωδικός Δοκιμίου	Περιοχή Ελέγχου (cm)	pH
Κ1 Ισογείου	0.0 – 4.0	9.1	Δ3 2ου Ορόφου	0.0 – 6.0	9.6
	5.0 – 13.0	11.8		7.0 – 11.5	11.5
Δ3 Ισογείου	0.0 – 8.0	11.9	Κ3 3ου Ορόφου	0.0 – 3.0	12.1
	9.0 – 11.0	12.1		4.0 – 14.0	12.3
Κ2 1ου Ορόφου	0.0 – 6.0	8.9	Δ3 3ου Ορόφου	0.0 – 8.0	8.6
	7.0 – 12.2	11.9		9.0 – 11.0	11.6
Δ1 1ου Ορόφου	0.0 – 6.0	10.7	Κ2 4ου Ορόφου	0.0 – 5.0	12.0
	7.0 – 12.1	12.1		6.0 -12.5	12.3
Κ2 2ου Ορόφου	0.0 – 4.0	10.4	Δ2 4ου Ορόφου	0.0 – 4.0	8.8
	5.0 – 8.5	12.1		5.0 – 11.0	11.9

Με βάση τα αποτελέσματα φαίνεται ότι το ποσοστό σε χλωριούχα (10/10) και θειικά (5/10) άλατα στα περισσότερα δοκίμια είναι πάνω από το μέγιστο επιτρεπτό.

Αρ./Θέση Δοκιμίου	By weight of sample Cl^- %	By weight of cement Cl^- %	By weight of sample SO3 %	By weight of cement SO_3 %
Κ1 Ισογείου	0.218	1.453	0.630	4.2
Δ3 Ισογείου	0.244	1.627	0.675	4.5
Κ2 1ου Ορόφου	0.303	2.020	0.570	3.8
Δ1 1ου Ορόφου	0.187	1.247	0.510	3.4
Κ2 2ου Ορόφου	0.166	1.107	0.660	4.4
Δ3 2ου Ορόφου	0.171	1.140	0.705	4.7
Κ3 3ου Ορόφου	0.356	2.373	0.540	3.6
Δ3 3ου Ορόφου	0.403	2.687	0.660	4.4
Κ2 4ου Ορόφου	0.092	0.613	0.585	3.9
Δ2 4ου Ορόφου	0.067	0.447	0.570	3.8
	Μέγιστη αποδεκτή περιεκτικότητα: 0.4% κατά βάρος τσιμέντου (by weight of cement) – BS8110 Μέγιστη αποδεκτή περιεκτικότητα: 0.2% κατά βάρος τσιμέντου (by weight of cement) – CYS300:2008			

*το πρότυπο BS1881 απαιτεί την έκφραση των αποτελεσμάτων κατά βάρος τσιμέντου στο δείγμα. Αυτό υποθέτουμε ότι είναι της τάξης του 15%.

- Αποτελέσματα εκτός μέγιστων ορίων σύμφωνα με τα πρότυπα BS8110 & CYS300:2008
- Αποτελέσματα εκτός μέγιστων ορίων σύμφωνα με το πρότυπο CYS300:2008 αλλά εντός σύμφωνα με το πρότυπο BS8110
- Αποτελέσματα εντός επιτρεπτών ορίων σύμφωνα με το πρότυπο CYS300:2008

Εντοπισμός οπλισμού με ηλεκτρομαγνητική μέθοδο (cover meter) & αποκαλύψεις

Σε τριάντα σημεία εντοπίστηκε ο οπλισμός με ηλεκτρομαγνητική μέθοδο (cover meter) και σε πέντε σημεία έγινε αποκάλυψη του. Σε όλα τα σημεία που αποκαλύφθηκε ο οπλισμός ήταν οξειδωμένος και σε δυο από αυτά η διατομή του έχει αλλοιωθεί. Όλες οι λεπτομέρειες και τα σκίτσα παρουσιάζονται στο παράρτημα Α & Β.

4.0 ΑΞΙΟΛΟΓΗΣΗ ΑΠΟΤΕΛΕΣΜΑΤΩΝ

- Μετά από τον λεπτομερή οπτικό έλεγχο των δοκιμίων παρατηρείται:
  - Ψηλή μέχρι χαμηλή συμπύκνωση
  - Ψηλό ποσοστό πόρων και παρουσία κυψελίδων (σε 13 δοκίμια)
  - Ελλιπής κοκκομετρική διαβάθμιση των υλικών του σκυροδέματος (χαμηλό ποσοστό σκύρων μεγέθους 20mm και αυξημένο ποσοστό λεπτόκοκκης άμμου)
  - Ελαφριά αποκόλληση αδρανών (σε έξι δοκίμια)

- Από τα αποτελέσματα της θλιπτική αντοχής φαίνεται ότι τα δεκαεννιά (63%) από τα τριάντα δοκίμια παρουσίασαν ικανοποιητικά αποτελέσματα. Τέσσερα από τα έντεκα δοκίμια που παρουσίασαν χαμηλή θλιπτική αντοχή εξήχθηκαν από τις κολώνες (26% των δοκιμίων που εξήχθηκαν από τις κολώνες). Τα δυο δοκίμια εξήχθηκαν από το ισόγειο και τα άλλα δυο από τον τέταρτο όροφο. Εδώ είναι σημαντικό να τονιστεί ότι η αξιολόγηση των αποτελεσμάτων της θλιπτικής αντοχής βασίζεται στην υπόθεση ότι η κατηγορία του σκυροδέματος που χρησιμοποιήθηκε στις κολώνες ήταν C20/25 και στις δοκούς ήταν C15/20.

- Η ενανθράκωση στα είκοσι οκτώ από τα τριάντα δοκίμια έχει προχωρήσει σε σημαντικό βαθμό πέραν του πάχους της επικάλυψης του οπλισμού (cover) που υπολογίζεται να είναι της τάξης των 2.0cm.

- Η αλκαλικότητα στη εξωτερική επιφάνεια του σκυροδέματος στα περισσότερα δοκίμια έχει μειωθεί σε πολύ μεγάλο βαθμό. Ανησυχητικό κρίνεται το γεγονός ότι μειωμένη αλκαλικότητα έχει εντοπιστεί και σε μεγαλύτερο βάθος (≈8cm)

- Από τις χημικές αναλύσεις φαίνεται ότι σε όλα τα δοκίμια που ελέγχθηκαν το ποσοστό περιεκτικότητας σε χλωριούχα άλατα είναι κατά πολύ ψηλότερο από το μέγιστο επιτρεπτό. Επίσης όσον αφορά το ποσοστό περιεκτικότητας σε θειικά άλατα στα πέντε από τα δέκα δοκίμια είναι ελαφρώς πέραν του μέγιστου επιτρεπτού ορίου. Εδώ πρέπει να σημειωθεί ότι τα αποτελέσματα πρέπει να κριθούν με ιδιαίτερη προσοχή διότι τα αποτελέσματα βασίζονται στην εκτίμηση ότι η ποσότητα του τσιμέντου στο σκυρόδεμα είναι της τάξης του 15%.

- Από τις πέντε αποκαλύψεις που έγιναν, εντοπίστηκε πως ο οπλισμός ήταν σε όλα τα σημεία οξειδωμένος. Σε δύο από αυτά η διατομή του οπλισμού είχε αλλοιωθεί.

CYS EN 12504-1 – Testing concrete in structures
ored specimens – Taking, examining and testing in compression

λάτης / Εργολάβος ent / Contractor	ΖΗΝΩΝ Α. ΖΗΝΩΝΟΣ (Κωδικός Εργασίας 17ΕΚΔ34)		
›γο ›ject	ΠΟΛΥΚΑΤΟΙΚΙΑ ΤΑΝΤΑ ΣΤΗ ΓΕΡΜΑΣΟΓΕΙΑ – ΛΕΜΕΣΟΣ		
ιβλέπων pervisor	ΖΗΝΩΝ Α. ΖΗΝΩΝΟΣ (ΑΡΧ.) & ΠΛΑΤΩΝΑΣ ΣΤΥΛΙΑΝΟΥ (Π.Μ.)		
ιερομηνία Ελέγχου te if testing	05/04/2017	Ημερομηνία Εξαγωγής Date of extraction	29&30/03/2017
οιχείο Ελέγχου sting member	Έχουν εξαχθεί συνολικά τριάντα κυλινδρικά δοκίμια από τις κολώνες και τις δοκούς της πολυκατοικίας		

τόκλιση από διαδικασία πρότυπης δοκιμής n conformity to standard method	ΝΑΙ YES	ΟΧΙ NO	Σε περίπτωση απόκλισης βλέπε σχόλια / if yes see comments below:

λωση/ Declaration
taking, examining and testing in compression was determined according to CYS EN 12504-1
αποτελέσματα αφορούν μόνο το δείγμα ελέγχου.
results are related only to the sample tested.
αγορεύεται η αναπαραγωγή του εντύπου χωρίς έγκριση της Geoinvest Ltd
reproduction of this document is not allowed without approval by Geoinvest Ltd
τωματισμός των επιφανειών θραύσης έγινε με ισοπό
ά τον έλεγχο τα δοκίμια ήταν επιφανειακά στεγνά (Saturated Surface Dry)
δοκίμια παρέμειναν 48 ώρες σε δεξαμενή νερού σε θερμοκρασία 20 °C

Κωδικός Δοκιμίου	Περιγραφή	Οπλισμός	Σχόλια
Κ1 γογείου	Το σκυρόδεμα των δοκιμίων αποτελείται από θραυστά διαβασικά σκύρα και φυσική άμμο (μέγιστο μέγεθος σκύρων: 20mm) Παρατηρείται αυξημένο ποσοστό πλακοειδών σκύρων, μειωμένο ποσοστό σκύρων μεγέθους 20mm και αυξημένο ποσοστό λεπτόκοκκης άμμου	/	/
Κ2 γογείου		/	Παρατηρούνται κυψελίδες και ελαφριά αποκόλληση λεπτόκοκκων αδρανών
Κ3 γογείου		/	Παρατηρούνται κυψελίδες
Δ1 γογείου		/	Παρατηρείται ελαφριά αποκόλληση αδρανών
Δ2 γογείου		/	/
Δ3 γογείου		/	/
Κ1 ' Ορόφου		/	Παρατηρούνται κυψελίδες
Κ2 ' Ορόφου		/	Παρατηρούνται κυψελίδες
Κ3 ' Ορόφου		/	/

Κωδικός Δοκιμίου	Περιγραφή	Οπλισμός	Σχόλια
Δ1 1ου Ορόφου	Το σκυρόδεμα των δοκιμίων αποτελείται από θραυστά διαβασικά σκύρα και φυσική άμμο (μέγιστο μέγεθος σκύρων: 20mm) Παρατηρείται αυξημένο ποσοστό πλακοειδών σκύρων, μειωμένο ποσοστό σκύρων μεγέθους 20mm και αυξημένο ποσοστό λεπτόκοκκης άμμου	/	/
Δ2 1ου Ορόφου		/	Παρατηρούνται κυψελίδες
Δ3 1ου Ορόφου		/	Παρατηρείται ελαφριά αποκόλληση αδρανών
Κ1 2ου Ορόφου		/	Παρατηρούνται κυψελίδες
Κ2 2ου Ορόφου		/	Παρατηρούνται κυψελίδες
Κ3 2ου Ορόφου		/	/
Δ1 2ου Ορόφου		/	/
Δ2 2ου Ορόφου		/	/
Δ3 2ου Ορόφου		/	Παρατηρούνται κυψελίδες
Κ1 3ου Ορόφου		/	/
Κ2 3ου Ορόφου		/	/
Κ3 3ου Ορόφου		/	/
Κ4 3ου Ορόφου		/	Παρατηρούνται κυψελίδες
Δ1 3ου Ορόφου		/	Παρατηρούνται κυψελίδες και ελαφριά αποκόλληση λεπτόκοκκων αδρανών
Δ2 3ου Ορόφου		/	Παρατηρούνται κυψελίδες και ελαφριά αποκόλληση λεπτόκοκκων αδρανών
Δ3 3ου Ορόφου		/	/
Δ4 3ου Ορόφου		/	/
Κ1 4ου Ορόφου		/	Παρατηρείται ελαφριά αποκόλληση αδρανών
Κ2 4ου Ορόφου		/	/
Δ1 4ου Ορόφου		/	Παρατηρούνται μικρές κυψελίδες
Δ2 4ου Ορόφου		/	Παρατηρούνται κυψελίδες

α/α	D (mm)	L bc mm	L mm	λ	A (mm^2)	LOAD (N)	ST/GTH of Core* (N/mm^2)	C1	ξ	ST/GTH of Cube** (N/mm^2)
K1 Ισ	74.6	130	77.4	1.038	4370.9	102470	23.4	1.015	1	23.8
K2 Ισ	74.6	120	78.4	1.051	4370.9	63110	14.4	1.020	1	14.7
K3 Ισ	74.6	125	77.6	1.040	4370.9	67520	15.4	1.016	1	15.7
Δ1 Ισ	74.6	125	79.9	1.071	4370.9	57620	13.2	1.027	1	13.5
Δ2 Ισ	74.6	132	79.5	1.066	4370.9	78990	18.1	1.025	1	18.5
Δ3 Ισ	74.6	110	76.7	1.028	4370.9	44130	10.1	1.011	1	10.2
K1 1ου	74.6	120	74.6	1.000	4370.9	156530	35.8	1.000	1	35.8
K2 1ου	74.6	122	78.1	1.047	4370.9	95740	21.9	1.018	1	22.3
K3 1ου	74.6	130	76.8	1.029	4370.9	129500	29.6	1.012	1	30.0
Δ1 1ου	74.6	121	81.7	1.095	4370.9	80460	18.4	1.036	1	19.1
Δ2 1ου	74.6	131	77.3	1.036	4370.9	94150	21.5	1.014	1	21.8
Δ3 1ου	74.6	115	77.9	1.044	4370.9	60000	13.7	1.017	1	14.0
K1 2ου	74.6	85	77.2	1.035	4370.9	133260	30.5	1.014	1	30.9
K2 2ου	74.6	121	79.3	1.063	4370.9	86450	19.8	1.024	1	20.3
K3 2ου	74.6	141	80.0	1.072	4370.9	99480	22.8	1.028	1	23.4
Δ1 2ου	74.6	110	79.4	1.064	4370.9	58270	13.3	1.025	1	13.7
Δ2 2ου	74.6	133	79.8	1.070	4370.9	95020	21.7	1.027	1	22.3
Δ3 2ου	74.6	115	77.8	1.043	4370.9	52360	12.0	1.017	1	12.2
K1 3ου	74.6	105	82.5	1.106	4370.9	169290	38.7	1.040	1	40.3
K2 3ου	74.6	141	78.3	1.050	4370.9	102640	23.5	1.019	1	23.9
K3 3ου	74.6	140	81.0	1.086	4370.9	141610	32.4	1.033	1	33.5
K4 3ου	74.6	121	80.2	1.075	4370.9	98510	22.5	1.029	1	23.2
Δ1 3ου	74.6	125	82.1	1.101	4370.9	46790	10.7	1.038	1	11.1
Δ2 3ου	74.6	130	79.8	1.070	4370.9	75800	17.3	1.027	1	17.8
Δ3 3ου	74.6	110	76.5	1.025	4370.9	57300	13.1	1.010	1	13.2
Δ4 3ου	74.6	110	79.4	1.064	4370.9	56240	12.9	1.025	1	13.2
K1 4ου	74.6	110	79.7	1.068	4370.9	25750	5.9	1.026	1	6.0
K2 4ου	74.6	125	79.9	1.071	4370.9	63880	14.6	1.027	1	15.0
Δ1 4ου	74.6	110	80.0	1.072	4370.9	101340	23.2	1.028	1	23.8
Δ2 4ου	74.6	110	79.9	1.071	4370.9	55610	12.7	1.027	1	13.1

D = diameter of core in mm
L = length of core in mm
λ = L/D
A = area of compressive edge in mm² = (π*D²) /4
LOAD = load in Newtons
ST/GTH = strength in N/mm²
WT = weight of core in grams

C1 = correction factor
C1=2.5/ (1.5+1/λ) for horizontal specimen (columns)
C1=2.3/ (1.5+1/λ) for vertical specimen (slabs)
ξ = correction for steel reinforcement
ξ = 1.0+1.5Σ*(($Φ_r$ *d) / ($Φ_c$ *l))
$Φ_r$ = diameter of steel reinforcement
$Φ_c$ = diameter of specimen
d = distance of bar axis to the nearest specimen edge
l = length of specimen before capping

Σχόλια – Discussions

*Ο υπολογισμός της θλιπτικής αντοχής έγινε με βάση το πρότυπο CYS EN 12504-1
**Ο υπολογισμός της θλιπτικής αντοχής έγινε με βάση το πρότυπο BS 1881-120

Ο πωματισμός των επιφανειών θραύσης έγινε με ισοπό / Κατά τον έλεγχο τα δοκίμια ήταν επιφανειακά στεγνά (Saturated Surface Dry) / Τα δοκίμια παρέμειναν 48 ώρες σε δεξαμενή νερού σε θερμοκρασία 20 °C.
Τα δοκίμια δεν παρέμειναν σε θερμοκρασία δωματίου τις πρώτες 48 ώρες. Μόλις παραλήφθηκαν στο εργαστήριο έγινε ο πωματισμός και τοποθετήθηκαν σε δεξαμενή νερού σε θερμοκρασία 20 °C.

Η αναφερόμενη αβεβαιότητα των μετρήσεων υπολογίσθηκε σε επίπεδο διπλάσιας τυπικής απόκλισης (αντιστοιχούσης στη περίπτωση της κανονικής κατανομής σε συντελεστή εμπιστοσύνης 95% κατά προσέγγιση. The measurement uncertainty stated in this report is estimated at the level of twice the standard deviation (corresponding, in the case of normal distribution, to a coefficient level of about 95%)

Η αναφερόμενη διευρυμένη αβεβαιότητα της μέτρησης είναι **1.3%**
The report expanded uncertainty of measurement is **1.3%**

10.2 Existing and Added Data.

PSA LLC was provided with some architectural plans and some structural drawings only. In any case, the drawings provided was a valuable source to understand / recognise the different components of the structure.

Through the performed field survey the overall structural system was identified and imprinted and then new structural plan and sketches were produced.

10.3 Knowledge Levels.

Performance assessment according to EN1998 can be performed with a variety of approaches. Still, the use of more sophisticated, nonlinear approaches also requires a similar sophistication in the data available for the structure, codified via the definition of the appropriate knowledge' as shown in Table 1.

For the present case, the requirement was for nonlinear static analysis to be performed for verifying seismic performance. When applying EN1998, this requires the existence of structural information at Knowledge Level 2 (KL2), requiring extensive in-situ testing of materials or detailed "as-built" drawings complemented by limited testing.

Table 1: Eurocode 8-3 Knowledge levels and corresponding methods of analysis (LF: Lateral Force procedure, MRS: Modal Response Spectrum analysis), NLA: Non Linear Analysis and confidence factors (CF).

Knowledge Level	Geometry	Details	Materials	Analysis	CF
KL1	From original outline construction drawings with sample visual survey or from full survey	Simulated design in accordance with relevant practice and from limited in-situ inspection	Default values in accordance with standards of the time of construction and from limited in-situ testing	LF-MRS	CF_{KL1}
KL2		From incomplete original detailed construction drawings with limited in-situ inspection or from extended in-situ inspection	From original design specifications with limited in-situ testing or from extended in-situ testing	All	CF_{KL2}
KL3		From original detailed construction drawings with limited in-situ inspection or from comprehensive in-situ inspection	From original test reports with limited in-situ testing or from comprehensive in-situ testing	All	CF_{KL3}

EN1998 requirements also dictate the use of appropriate confidence factors to provide further safety given the incomplete information implied by knowledge levels lower than KL3.

The values ascribed to the confidence factors to be used in a country may be found in its National Annex. The recommended values, adopted by Cyprus Annex, are $CF_{KL1} = 1.35$, **$CF_{KL2} = 1.20$** and $CF_{KL3} = 1.00$.

10.4 Application Codes and Guidelines

For the analysis, the design checks as well as the assessment procedures, we have used the following codes:

a) EN1990 Basis of Structural Design
Cyprus National Annex to CYS EN 1990 Eurocode 1990

b) EN 1991 Actions on Structures
Cyprus National Annex to CYS EN 1991 Eurocode 1991

c) EN1992-1 Eurocode 2: Design of concrete Structures
Cyprus National Annex to CYS EN 1992 Eurocode 1992

d) EN1993-1 Eurocode 3: Design of Steel Structures
Cyprus National Annex to CYS EN 1992 Eurocode 1992

e) EN 1997 Eurocode 7: Geotechnical Design

f) EN1998-1 Eurocode 8: Design of Structures for Earthquake Resistance
Cyprus National Annex to CYS EN 1998 Eurocode 1998

g) EN 1998-3 Eurocode 8: Assessment and Retrofitting of Building
Cyprus National Annex to CYS EN 1998, Eurocode 1998

In addition to the above, further supporting guidelines were consulted on the issue of seismic assessment, mainly to provide guidance in applying nonlinear static methods:

a) ASCE/SEI Standard 41-06, Seismic rehabilitation of existing buildings, American Society of Civil Engineers

b) FEMA 356 and 547, techniques for the seismic rehabilitation of existing buildings.

10.5 Seismic Hazard

For the purposes of the current assessment, the design spectrums of Eurocode 8 was purely adopted. These spectrums were derived by the implementation of probabilistic seismic hazard analysis in the Cyprus seismotectonic - geological territory of the Eastern Mediterranean, since they comprise of a fairly good approximation of the actual seismic hazard.
The three limit states also adopted from Eurocode correspond to three probabilities of exceedance in a period of time of 50 years for a strong ground motion event:

The Near Collapse limit state (NC), corresponds to a seismic event with a probability of 2% to be exceeded in 50 years.

Significant Damage limit stat (SD) corresponds to a seismic event with a probability of 10% to be exceeded in 50 years, and finally

Damage Limitation limit state (DL), corresponds to a seismic event with a probability of 20% to be exceeded in 50 years.

10.6 Modelling

Models in any advanced software are mathematical representations which provide a means for predicting the response characteristics of a structure without actually building it, and subjecting the structure to the maximum loads or disturbances it is being designed to withstand.

Throughout the frame elements of the structure, non-linear plastic hinges are added – which serve the purpose of control points – in which the stress level increases gradually along with the gradually increased lateral loading. When a particular non-linear hinge reaches its failure point, load redistribution occurs with possible global yielding effects, or yielding of other nearby non-linear hinges. This way, the various weaknesses of the structure can be identified and monitored in a step-by-step procedure from the beginning of lateral load application towards reaching the target displacement. Moreover, with this approach retrofit decisions can be made easier.

In our case the building was modeled and analyzed using the ETABS Ultimate Version 18.0.0 code, by C.S.I.

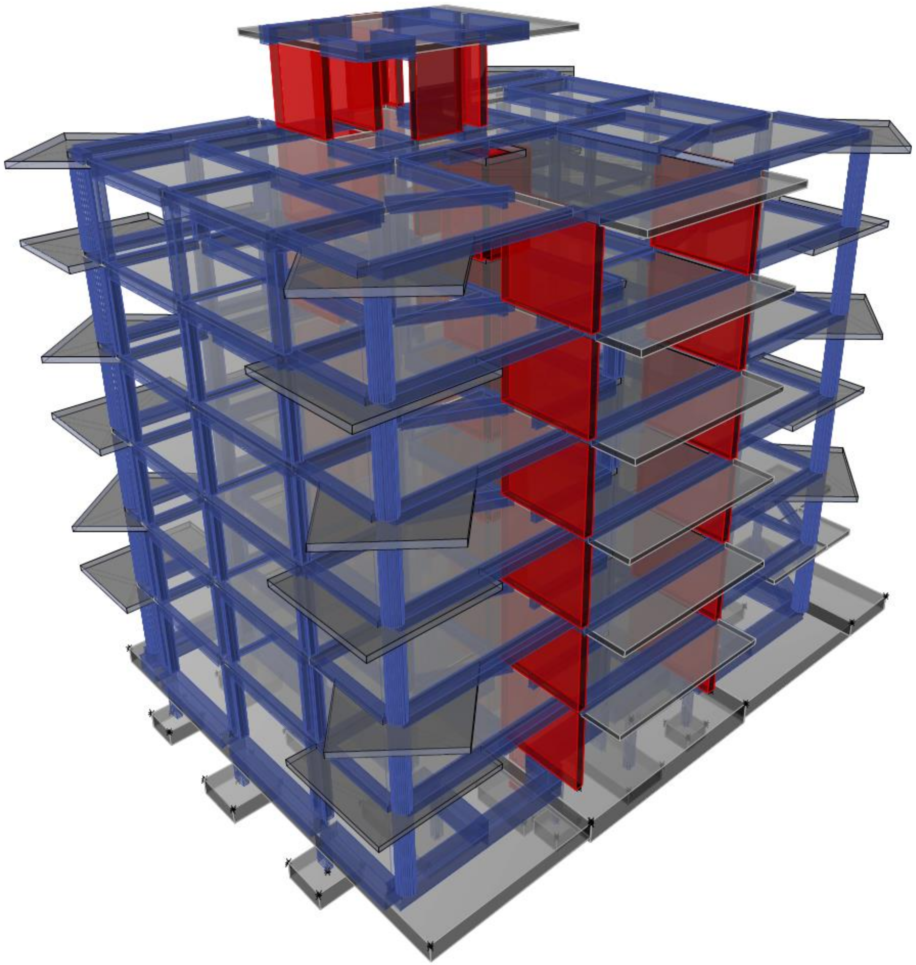


Figure 1: 3D Model Idealization

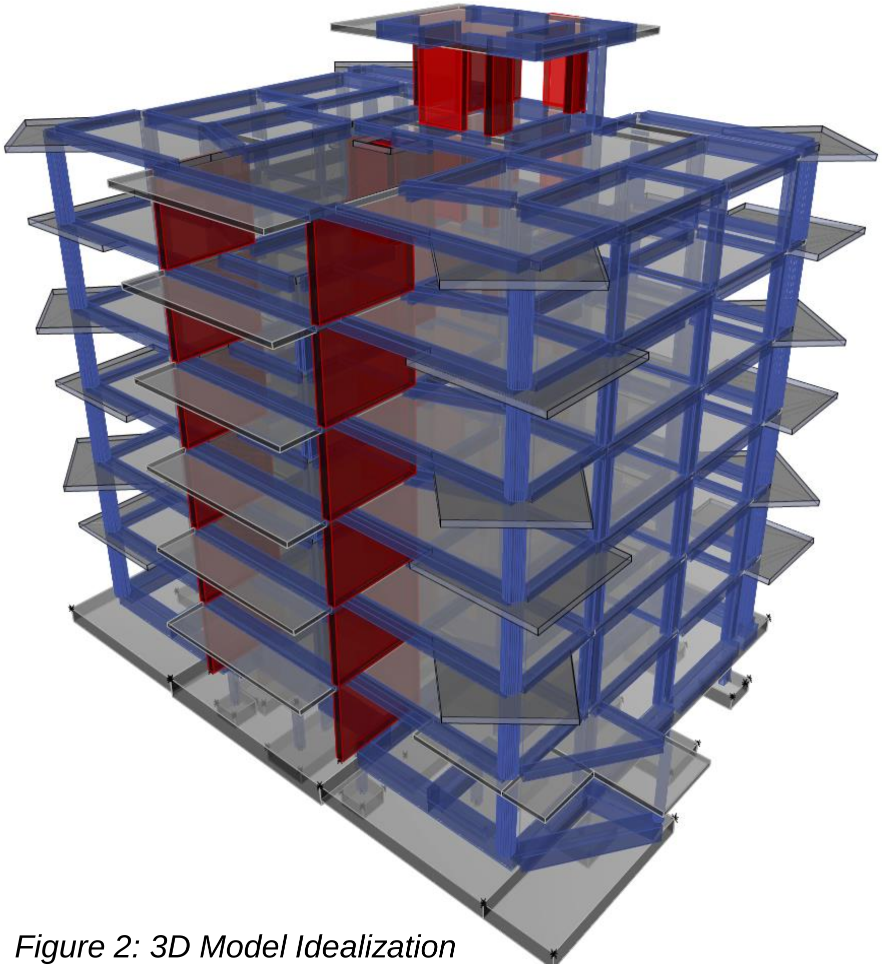


Figure 2: 3D Model Idealization

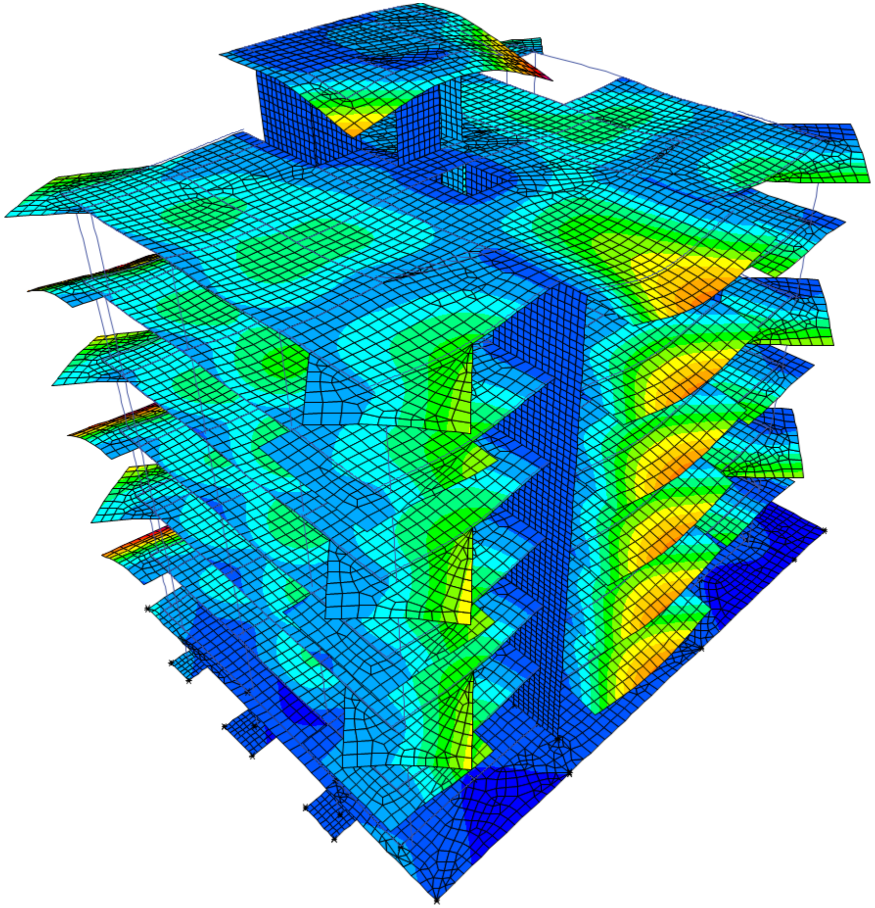


Figure 3: Deformed Shape under S.L.S combination G+Q

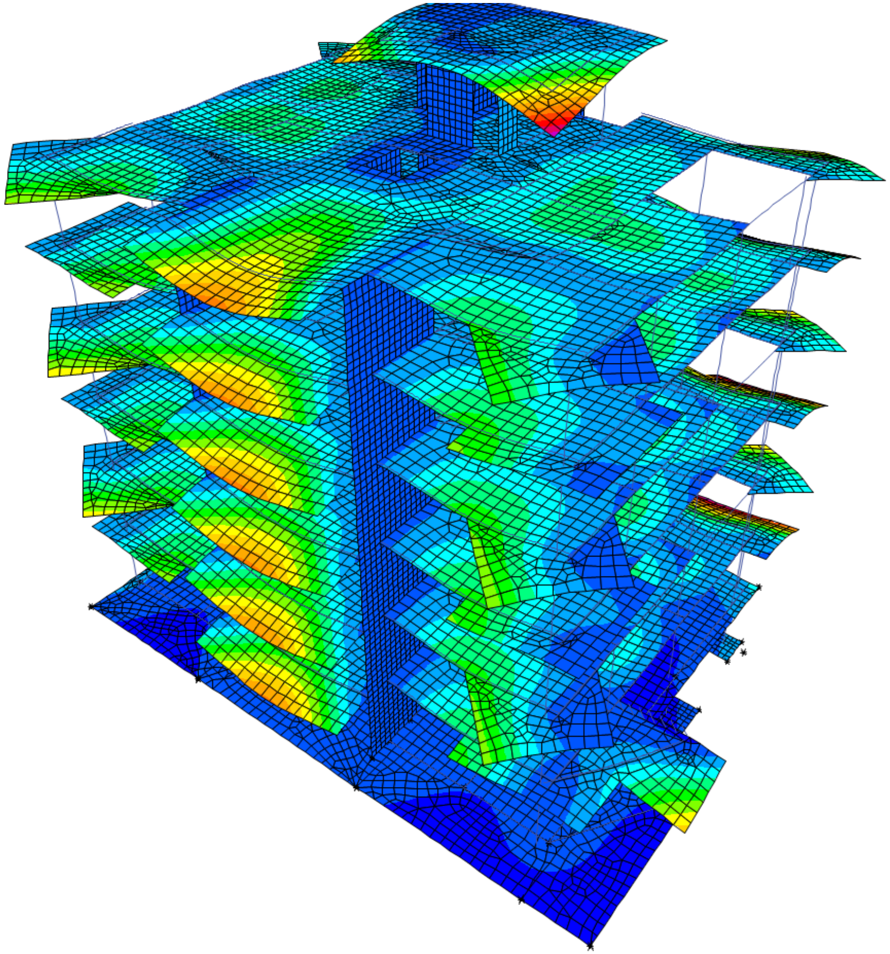


Figure 4: Deformed Shape under S.L.S combination G+Q

10.7 Structural Model

The structure was modelled using linear elements for RC beams and columns and shell elements for shear walls and RC slabs. Regarding the foundation system, fixity was assumed at the element bases. Overall dimensions, element sections and material properties included in the analysis model, were based on the survey drawings and findings, the photos taken on site and the laboratory results.

The building was designated together with the client to be of importance class II and hence **the design ground acceleration (0.25g) was multiplied by a factor of 1 according to the EC8 recommendations. Further to this, the material damping was set as 5% and the soil class was taken to be class B.**

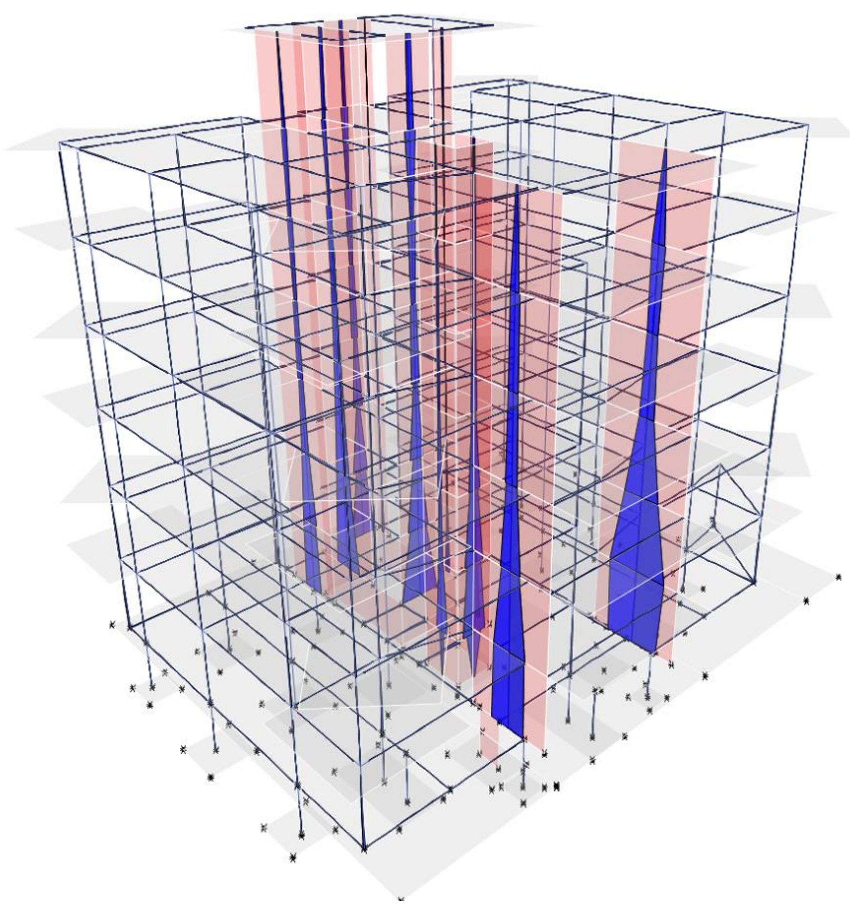


Figure 5: Pier Element main moment Range under U.L.S. Earthquake Combination in main X-direction.

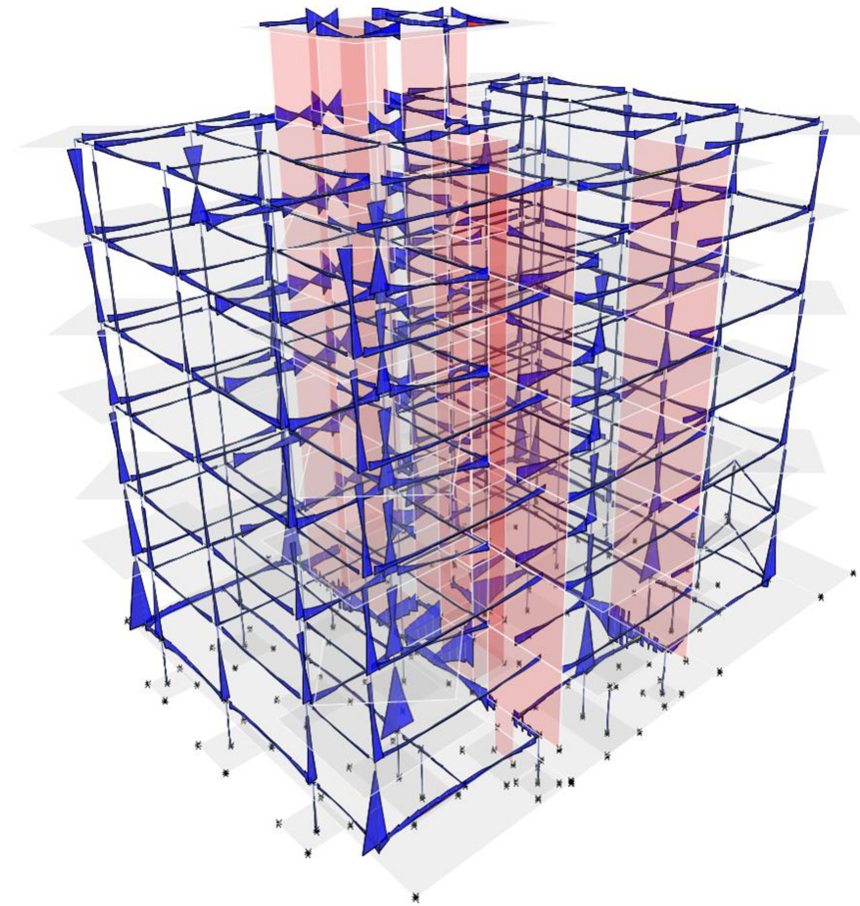


Figure 6: Frame Element main moment Range under U.L.S. Earthquake Combination in main X-direction.

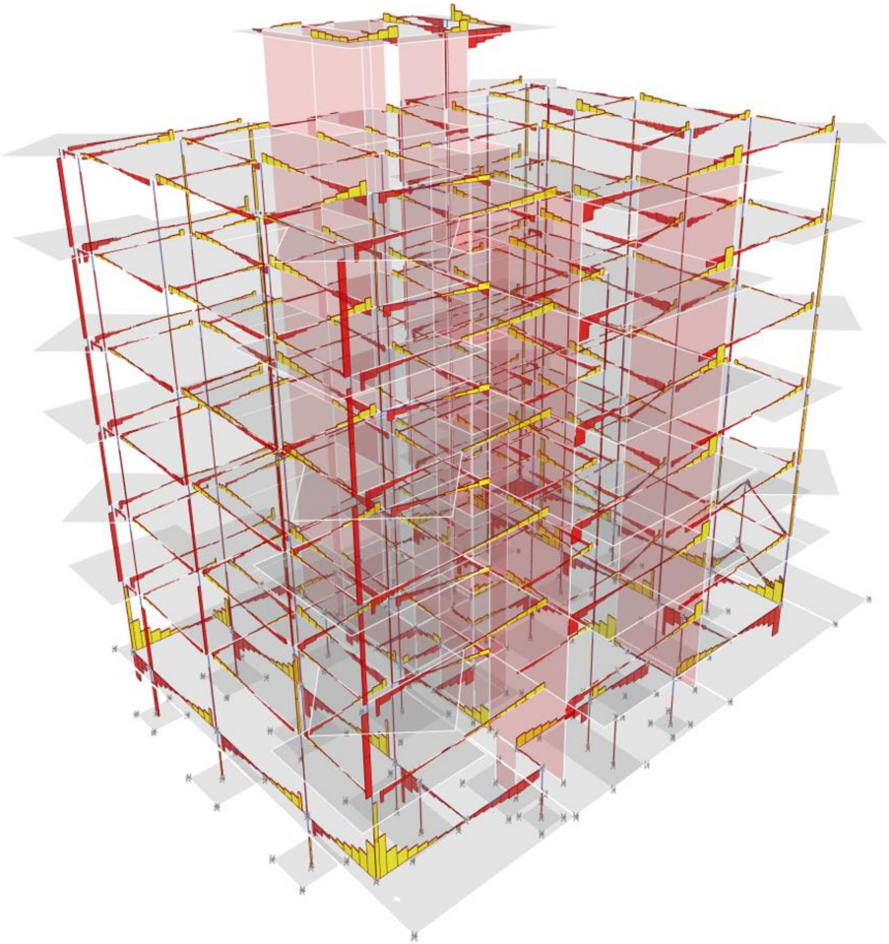


Figure 7: Frame Element main shears under U.L.S. combination 1.35G + 1.5Q.

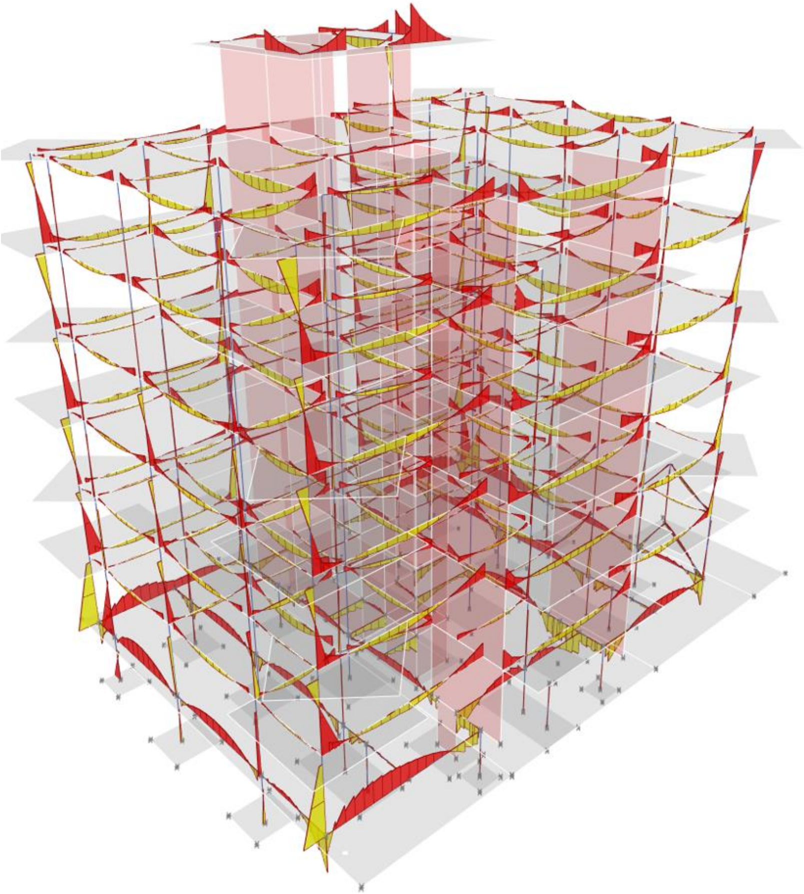
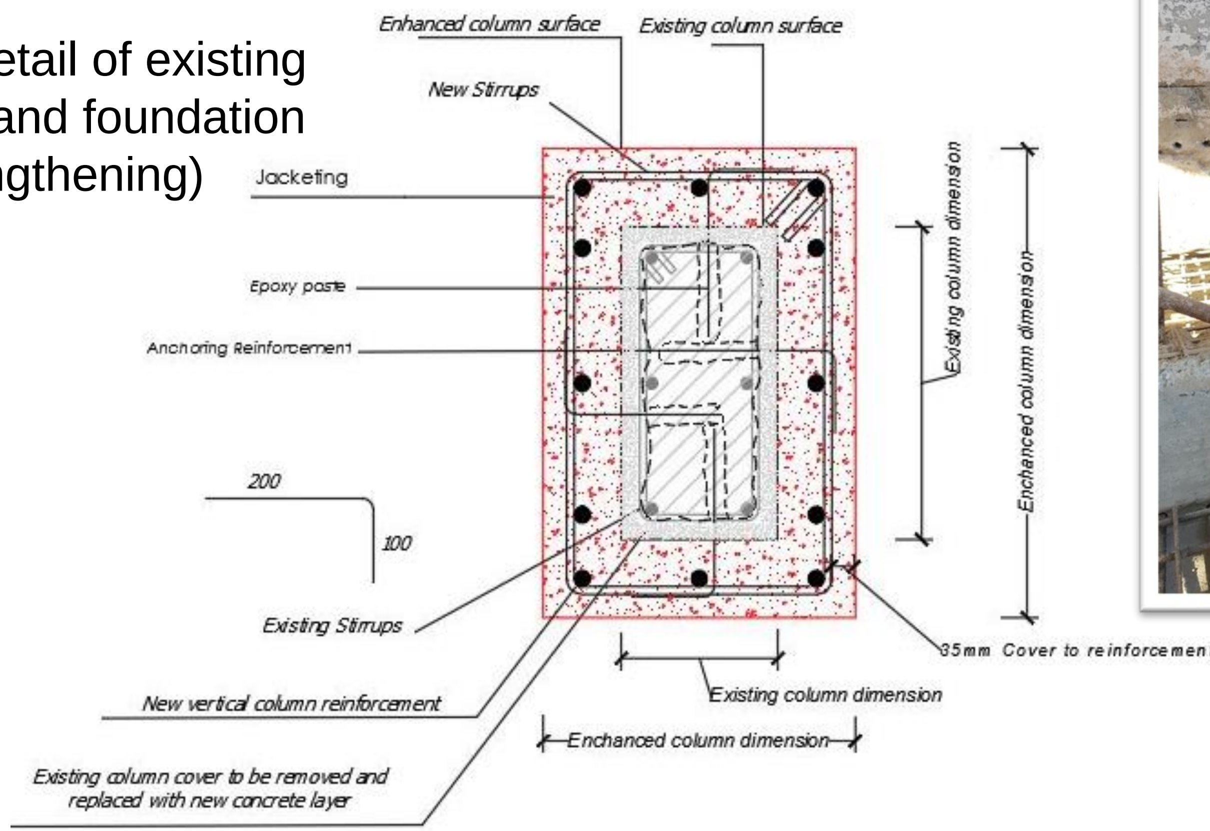


Figure 8: Frame Element main moments under U.L.S. combination 1.35G + 1.5Q.

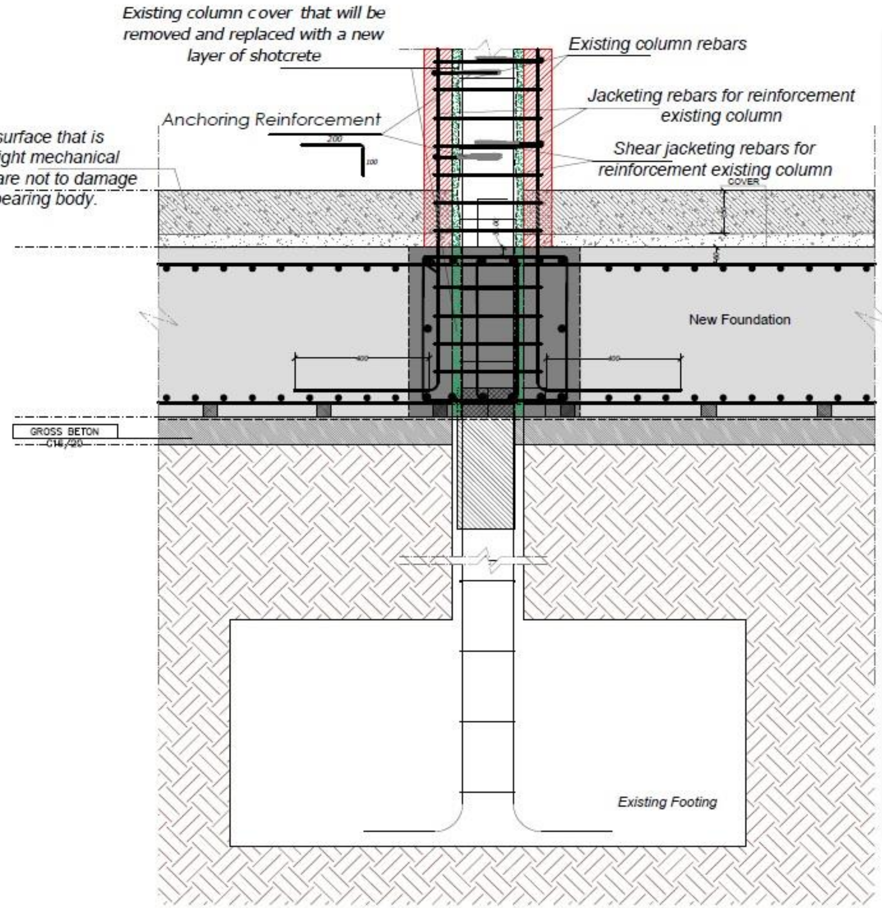
STRENGTHENING OF THE EXISTING BUILDING

(Jacketing Detail of existing columns and foundation strengthening)



STRENGTHENING OF THE EXISTING BUILDING

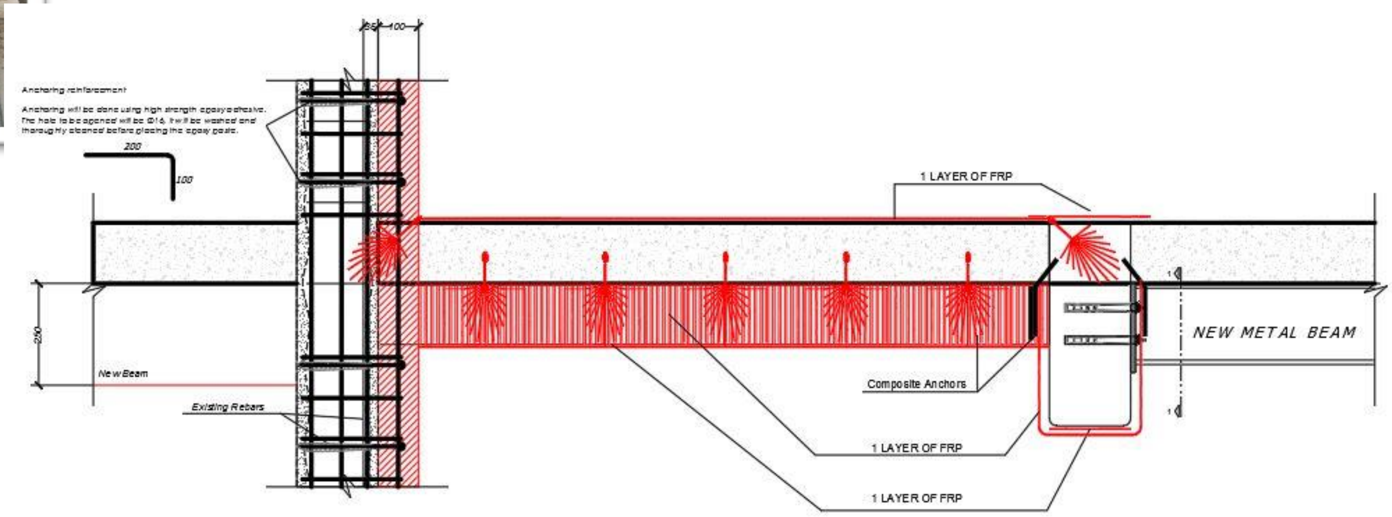
(new mat foundation which encased existing ground beams)



STRENGTHENING OF THE FOUNDATIONS OF THE EXISTING BUILDING

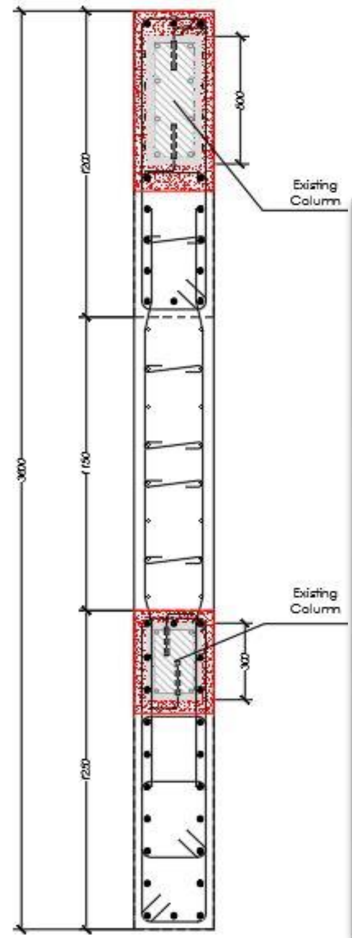
STRENGTHENING OF THE EXISTING BUILDING

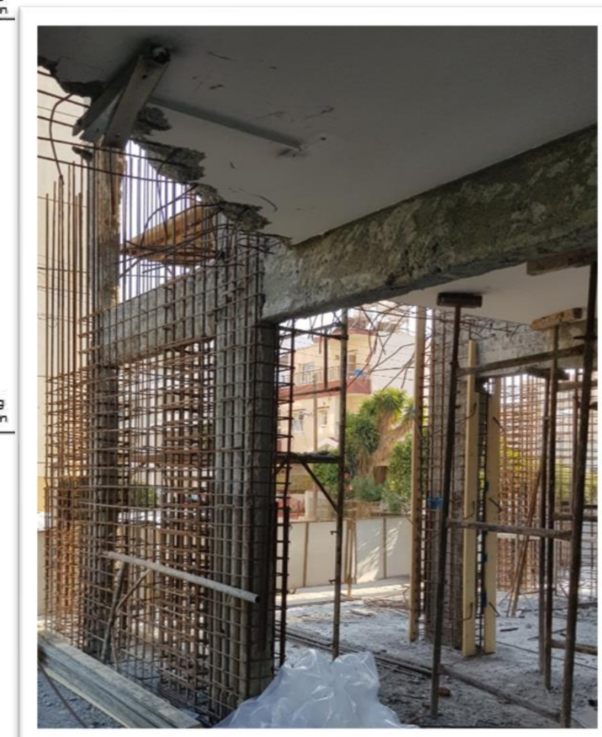
(Fibre Reinforced Polymers (FRP) - strengthening of beams /slabs)



STRENGTHENING OF THE EXISTING BUILDING

(formation of shear walls from existing columns)





STRENGTHENING OF THE EXISTING BUILDING

(Jacketing Detail of existing columns)

10.8 Performance and Risk Seismic Rehabilitation

A seismic risk assessment procedure **involves the novel concept of performance levels or objectives, used to define the targeted level of risk for the building investigated.** Their complex nature suggests that they should be carefully studied and discussed with building owners before use.

Generally, the terminology used for **target building Performance Levels** is intended to **represent goals of design**. Structures rehabilitated to a higher standard will always perform better than the ones designed to a lesser one.

Variations in actual performance could be associated with unknown geometry and member sizes in existing buildings, deterioration of materials, incomplete site data, variation of ground motion that can occur within a small area and incomplete knowledge and simplifications related to modeling and analysis (former FEMA 356).

10.8 Performance and Risk Seismic Rehabilitation

Building performance can be described qualitatively in terms of:

(a) the safety afforded to building occupants during and after the event;

(b) the cost and feasibility of restoring the building to pre-earthquake condition;

(c) the length of time the building is removed from service to effect repairs; and

(d) economic, architectural, or historic impacts on the larger community.

These performance characteristics are directly related to the extent of damage that would be sustained by the building. A broad range of target building performance levels may be selected when determining rehabilitation objectives.

Probabilistic earthquake hazard levels frequently used in relevant standard and their corresponding mean return periods (the average number of years between events of similar severity) are as shown in Table 2.

10.8 Performance and Risk Seismic Rehabilitation

Probability of Exceedance	Mean Return Period (years)*
20% / 50years (DL)	225
10% / 50years (SD)	475
2% / 50years (NC)	2475

*** These mean return periods are typically rounded to 225, 500 and 2500 years, respectively.**

Table 2: Earthquake probability of exceedance versus mean return period.

The rehabilitation objective selected as a basis for design will determine, to a great extent, the cost and feasibility of any rehabilitation project, as well as the benefit to be obtained in terms of improved safety, reduction in property damage, and interruption of use in the event of future earthquakes

10.9 Performance and Risk Seismic Rehabilitation

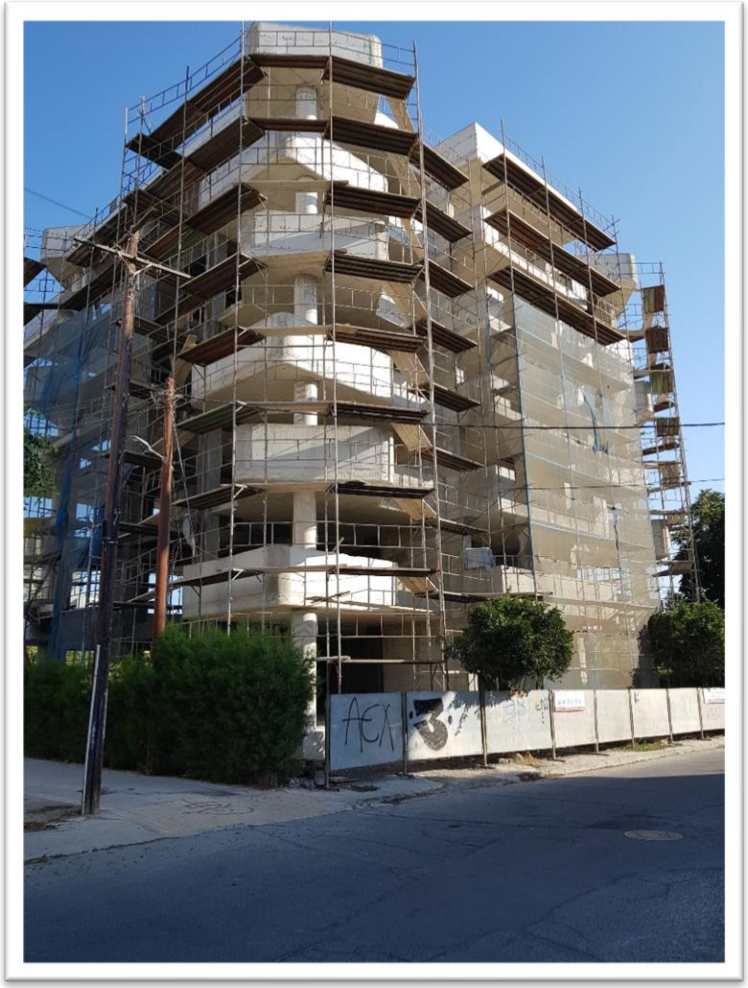
Regarding the strategy for assessing the seismic capacity of the building, the general parameters to be determined before the assessment of the existing structure and the evaluation of probable rehabilitation alternatives are the following:

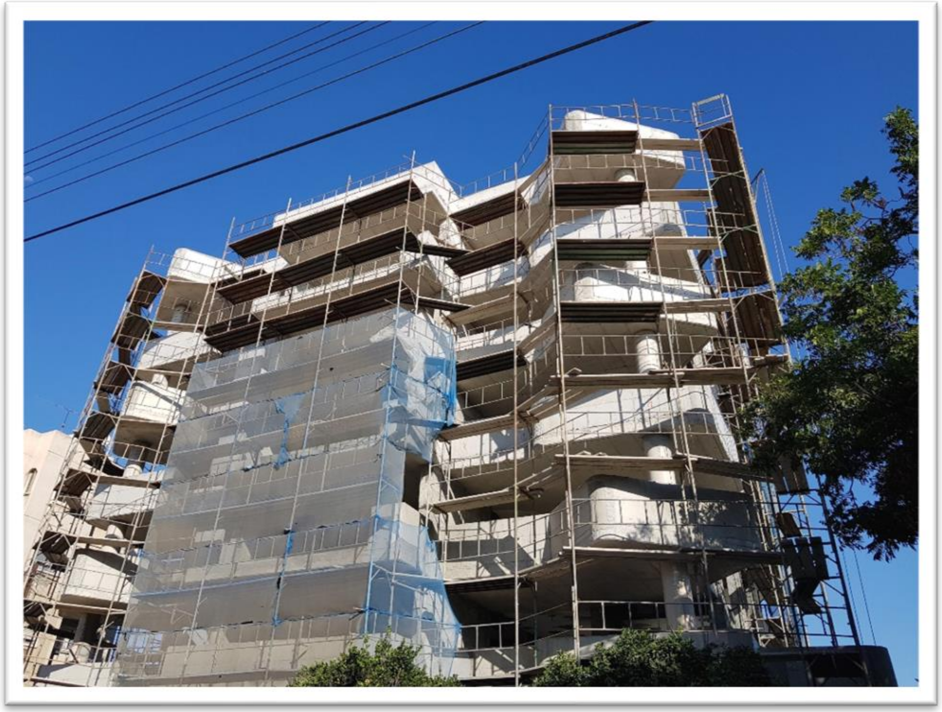
- The magnitude of the seismic action to be taken into account in the assessment and strengthening design (Codes & Annexes).
- The performance level that is acceptable for the structure and its subcomponents.

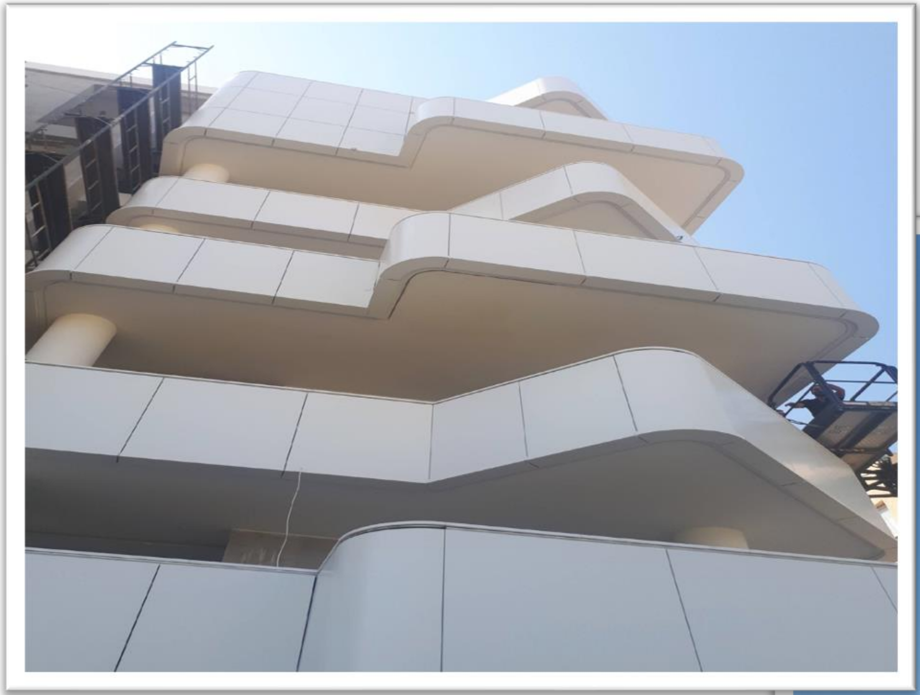
The combination of action and performance levels proposed by Eurocode 8 for our building was corresponding to level SD, thus multiplied by a factor of 1.0. The corresponding peak ground acceleration proposed in the Cyprus National Annex to Eurocode 8 for this level is 0.25g on rock at the location of the building.

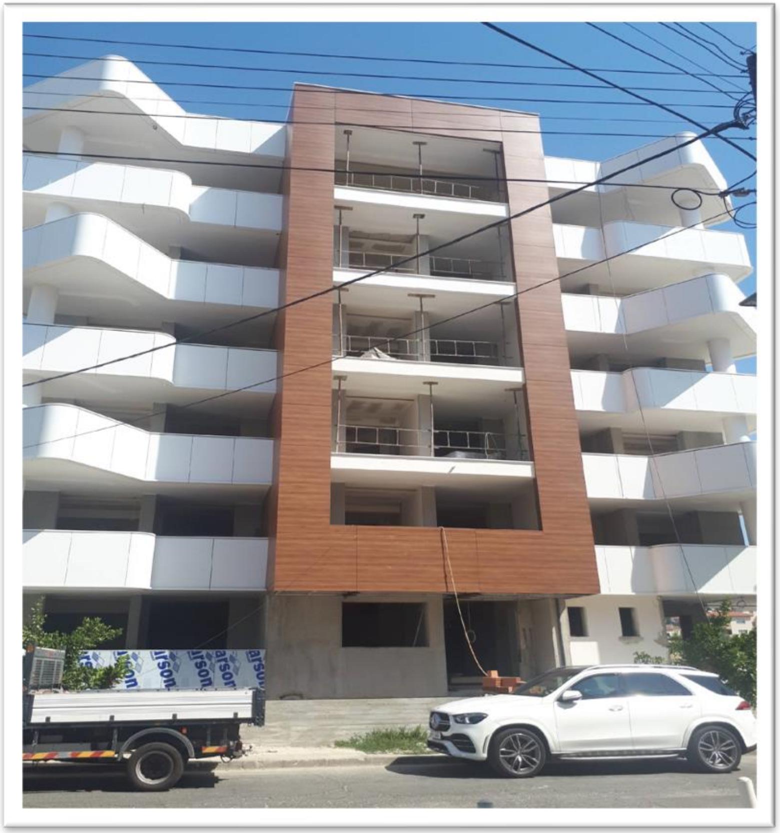
Thus considering the building function, we **suggested a a scheme of strengthening up to the level of a 10% exceedance probability in 50 years for the Significant Damage performance level.**

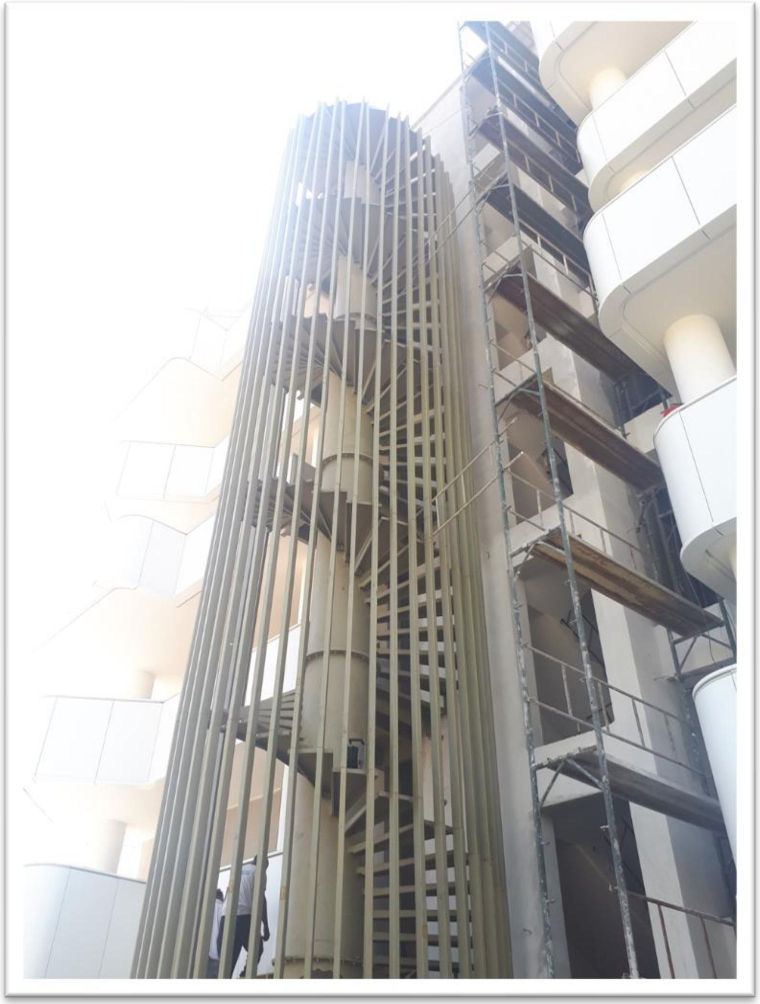
- **Photos after the structural/seismic strengthening – FINAL BUILDING**











THANK YOU FOR YOUR ATTENTION!