

Design and construction of skylight for The Spot Choueifat Mall in Beirut, Lebanon. Supports configuration to earthquake design

Mikel MONASTERIO*^a, David CABALLERO^a, Ibon VALLE^a, Josu GOÑI^a

*^a LANIK I, S.A.

Mundaiz 8, 20012, San Sebastián, Spain
mmonasterio@lanik.com

Abstract

The Spot Choueifat shopping mall opened to the public in 2017. This mall was designed by Design Novel Architecture, Dolmen and Adoca. The building has a 3000 m² and 34 m span gridshell made by Lanik. Despite its common span, the design of the structure became challenging due to the boundary conditions.

The skylight is supported on 7 different blocks joined by a courtyard. When seismic loads are applied on the concrete structure, each block has a different behaviour. Therefore, big relative displacements are overtaken between the top parts of the blocks, up to 200 mm. This became one of the main restrictions for the structural design.

First of all, if fixed supports had been used, the gridshell would have had to resist efforts caused by these displacements. On the other side, if sliding supports had been used, the structure could not have been designed as a compression shell and bigger beams would have been required. Therefore, a compromise solution was needed in order to optimize the structure. Displacements between different blocks were analysed and supports were set up accordingly: small displacement directions were fixed and large displacement directions were set free. Furthermore, controlled elastic supports made out of springs were also used. Set up with a higher stiffness in the support, the beams would have failed due to larger efforts; with lower stiffness, compression shell behaviour would have been lost, leading to larger efforts. Finding the required exact stiffness was one of the main goals in the project.

Finally, some sliding supports had a special design too. The forementioned large displacements and uplift caused by the wind required them. Supports had to allow 150 mm of displacement on each horizontal direction and had to retain the structure when uplift happened.

Keywords: gridshell, skylight, earthquake, support, Lanik.

1. Introduction

The Spot Choueifat shopping mall opened to the public in 2017. This mall was designed by Design Novel Architecture, Dolmen and Adoca. Lanik was contracted by Glassline Industries, which was responsible for all the skylights and façades, including structures and glazing. Lanik became involved in the project in 2013 and its final scope was the design and fabrication of 4 gridshells and the shop drawings of the glazing. Three of the gridshells, which cover an interior promenade, span 13 m on average and have 725 m², while the one that covers the central courtyard, spans 34 m and has 2235 m².



Figure 1: Central courtyard of The Spot Choueifat Mall [Lanik]

The shopping mall is formed by 7 buildings with different shapes and heights. As it is usual in earthquakes, although they are all joined in the ground floors, they have different behaviour on the top. The gridshell was developed as a compression gridshell in order to minimize the section of the beams and to obtain a cost-effective structure. However, as the supports were placed in the top of the aforementioned buildings, their seismic behaviour compromised all the design of the structure.



Figure 2: Initial renders of the project [Adoca www.adoca.co]

2. Main problem: contradiction

The first renders of the project of The Spot Choueifat Mall showed the current skylights, but with different geometries: flat structures and a central dome. At the early stages of the project, the initial flat skylights were transformed into a complete gridshell with double curvature.

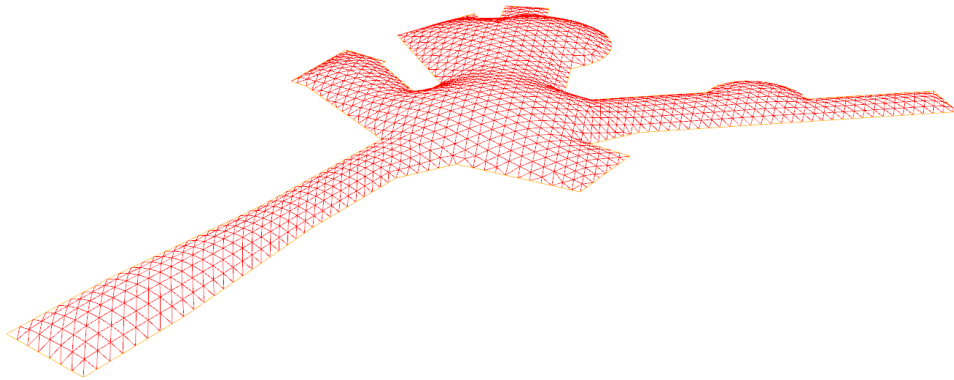


Figure 3: Structure wireframe of the first models as a compression gridshell [Lanik]

Compression shells lay their main principles in double curvature. In order to work properly as a shell, they need stiff supports. Therefore, loads on the structure are transmitted as compression and supports will receive a reaction not only in vertical direction but also in horizontal direction. The same process can be seen easily in 2D with arches as seen on Figure 4.

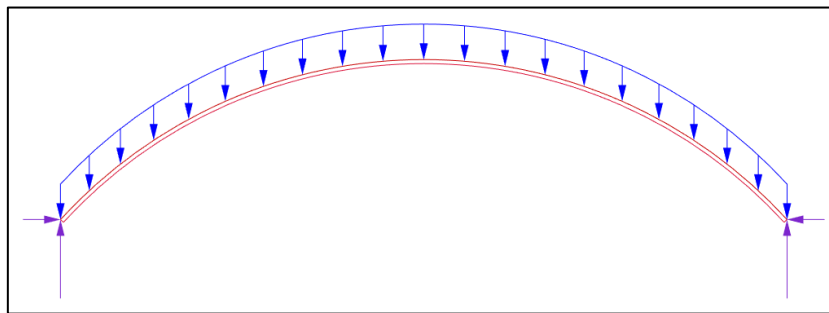


Figure 4: Loads and reactions of an arch[Lanik]

All these statements collided when seismic loads were applied to the structure. The aforementioned concrete buildings suffered large displacements on their top. These deformations were relative between the different blocks; as all the buildings have different shapes and dimensions, their behaviour was different. If the structure were fixed to all those buildings, it would try to retain all the displacements, leading to big efforts. Therefore, in order to avoid these efforts most of the support should have been sliding ones.

In conclusion, a contradiction was met at this stage: on the one hand, supports should have been fixed to take advantage of the compression shell properties, but on the other hand, sliding supports were recommended to avoid the large efforts caused by the displacements of the buildings during an earthquake.

One of the proposed solutions was the introduction of cables or tension rods. With them, the structure could be fixed to one of the buildings with fixed supports and be attached to other buildings only in vertical direction, using sliding supports. This solution has been used in many gridshells; for example, the town hall of Madrid, as shown in reference [3]. In that case, there was not any displacements problem, but horizontal reactions could not be transmitted to the original structure. Therefore, a cable net and a perimeter beam were disposed to balance those reactions and maintain the compression shell. This solution was not accepted by the final client, hence new solutions needed to be proposed.



Figure 5: Courtyard of the town hall of Madrid. Notice the slight cable net under the gridshell. [Lanik]

3. First solution: support configuration

	GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 6	GROUP 7
GROUP 1	NODE 208 188 180 176 156 137 117 105 82 57 33 10	NODE WXX WYY 208 11.16 10.16 188 10.59 10.17 180 10.03 10.17 176 9.47 10.17 156 8.91 10.18 137 8.35 10.18 117 7.78 10.18 105 7.22 10.19 82 6.66 10.19 57 6.10 10.19 33 5.54 10.20 10 4.97 10.20	NODE WXX WYY 208 10.59 9.76 188 10.00 9.53 180 9.40 9.30 176 8.81 9.07 156 8.21 8.84 137 7.62 8.60 117 7.02 8.37 105 6.43 8.14 82 5.83 7.91 57 5.24 7.68 33 4.65 7.45 10 4.05 7.22	NODE WXX WYY 208 11.59 5.49 188 11.08 5.40 180 10.56 5.31 176 10.05 5.22 156 9.54 5.13 137 9.02 5.04 117 8.51 4.95 105 8.00 4.86 82 7.48 4.77 57 6.97 4.68 33 6.45 4.59 10 5.94 4.50	NODE WXX WYY 208 10.03 5.53 188 9.78 5.46 180 9.53 5.39 176 9.29 5.31 156 9.04 5.24 137 8.79 5.17 117 8.55 5.10 105 8.30 5.03 82 8.05 4.96 57 7.81 4.89 33 7.56 4.82 10 7.31 4.75	NODE WXX WYY 208 14.56 11.86 188 14.68 11.50 180 14.79 11.15 176 14.90 10.80 156 15.02 10.44 137 15.13 10.09 117 15.24 9.74 105 15.36 9.39 82 15.47 9.03 57 15.58 8.68 33 15.70 8.33 10 15.81 7.97
	NODE WXX WYY 18 4.97 10.20 28 5.42 10.20 48 5.86 10.19 38 6.30 10.19 29 6.74 10.19 23 7.18 10.19 19 7.62 10.18 6 8.07 10.18 2 8.51 10.18 3 9.39 10.17 5 9.83 10.17 9 10.27 10.17 24 10.71 10.17 43 11.16 10.16	NODE 18 28 48 38 29 23 19 6 2 3 5 9 24 43	NODE WXX WYY 18 5.46 11.34 28 5.20 10.69 48 4.93 10.04 38 4.67 9.40 29 4.40 8.75 23 4.13 8.10 19 3.87 7.45 6 3.60 6.80 2 3.34 6.15 3 2.81 4.85 5 2.54 4.21 9 2.28 3.56 24 2.01 2.91 43 1.75 2.26	NODE WXX WYY 18 7.06 9.88 28 6.93 9.59 48 6.80 9.29 38 6.67 9.00 29 6.54 8.71 23 6.41 8.41 19 6.28 8.12 6 6.15 7.83 2 6.02 7.53 3 5.76 6.95 5 5.64 6.66 9 5.51 6.36 24 5.38 6.07 43 5.25 5.78	NODE WXX WYY 18 7.99 11.25 28 7.96 10.86 48 7.94 10.48 38 7.92 10.10 29 7.90 9.71 23 7.88 9.33 19 7.86 8.94 6 7.83 8.56 2 7.81 8.17 3 7.77 7.40 5 7.75 7.02 9 7.73 6.63 24 7.70 6.25 43 7.68 5.86	NODE WXX WYY 18 16.94 15.73 28 16.92 15.31 48 16.91 14.89 38 16.89 14.47 29 16.88 14.05 23 16.86 13.62 19 16.85 13.20 6 16.83 12.78 2 16.82 12.36 3 16.79 11.52 5 16.77 11.10 9 16.76 10.68 24 16.74 10.26 43 16.73 9.84
	NODE WXX WYY 54 4.35 7.33 65 4.65 7.45 81 4.94 7.56 91 5.24 7.68 104 5.54 7.79 115 5.83 7.91 136 6.13 8.03 148 6.43 8.14 166 6.73 8.26 179 7.02 8.37 207 7.32 8.49 222 7.62 8.60 224 7.92 8.72 235 8.21 8.84 247 8.51 8.95 256 8.81 9.07 271 9.11 9.18 288 9.40 9.30 301 9.70 9.41 316 10.00 9.53 289 10.30 9.64	NODE WXX WYY 54 1.92 2.67 65 2.09 3.08 81 2.26 3.50 91 2.42 3.91 104 2.59 4.32 115 2.76 4.74 136 2.93 5.15 148 3.10 5.56 166 3.27 5.97 179 3.44 6.39 207 3.60 6.80 222 3.77 7.21 224 3.94 7.63 235 4.11 8.04 247 4.28 8.45 256 4.45 8.86 271 4.62 9.28 288 4.79 9.69 301 4.95 10.10 316 5.12 10.52 289 5.29 10.93	NODE 54 65 81 91 104 115 136 148 166 179 207 222 224 235 247 256 271 288 301 316 289	NODE WXX WYY 54 4.77 3.54 65 4.68 3.61 81 4.59 3.68 91 4.49 3.75 104 4.40 3.82 115 4.31 3.89 136 4.22 3.96 148 4.13 4.03 166 4.04 4.10 179 3.95 4.17 207 3.86 4.23 222 3.77 4.30 224 3.68 4.37 235 3.59 4.44 247 3.49 4.51 256 3.40 4.58 271 3.31 4.65 288 3.22 4.72 301 3.13 4.79 316 3.04 4.86 289 2.95 4.93	NODE WXX WYY 54 7.14 4.79 65 7.01 4.81 81 6.88 4.84 91 6.74 4.86 104 6.61 4.88 115 6.47 4.91 136 6.34 4.93 148 6.21 4.96 166 6.07 4.98 179 5.94 5.00 207 5.80 5.03 222 5.67 5.05 224 5.53 5.08 235 5.40 5.10 247 5.27 5.12 256 5.13 5.15 271 5.00 5.17 288 4.86 5.20 301 4.73 5.22 316 4.60 5.24 289 4.46 5.27	NODE WXX WYY 54 16.17 10.54 65 16.09 10.48 81 16.00 10.42 91 15.92 10.36 104 15.84 10.31 115 15.75 10.25 136 15.67 10.19 148 15.59 10.13 166 15.50 10.07 179 15.42 10.01 207 15.34 9.95 222 15.25 9.89 224 15.17 9.84 235 15.09 9.78 247 15.00 9.72 256 14.92 9.66 271 14.84 9.60 288 14.75 9.54 301 14.67 9.48 316 14.59 9.42 289 14.50 9.37

Figure 6: Extract from the displacements matrix provided by the engineering firm Adoca (centimeters) [Lanik]

In order to reach a compromise solution, deformations of the buildings were studied. The engineering firm Adoca provided all the displacements in a matrix where the relative displacements between pairs of blocks were showed: Figure 6. Apart from the mentioned 7 buildings, the gridshell was supported in other 3 trusses.

The analysis of the displacements showed that on the one hand some of the buildings had large relative displacements between them, and on the other hand, other ones did not. After that, the solution was oriented in one direction: the change of supports' configuration. The structure would be fixed to one of the blocks, and it would be fixed to the others depending on the relative displacements with the fixed one while buildings with big relative displacements would have sliding supports.

After some iteration, the supports' configuration reached the stage of Figure 7. The structure was fixed to block number 1 so fixed supports were used on it. On the contrary, block number 3 was totally freed horizontally due to its big displacements. Buildings 2, 4, 6 and 7 would have supports fixed in Y direction and sliding in X. This stiffness in Y axis would allow the structure to work as a gridshell on its main direction. Finally, supports on the trusses were designed as sliding supports, in order to avoid horizontal reactions over them.

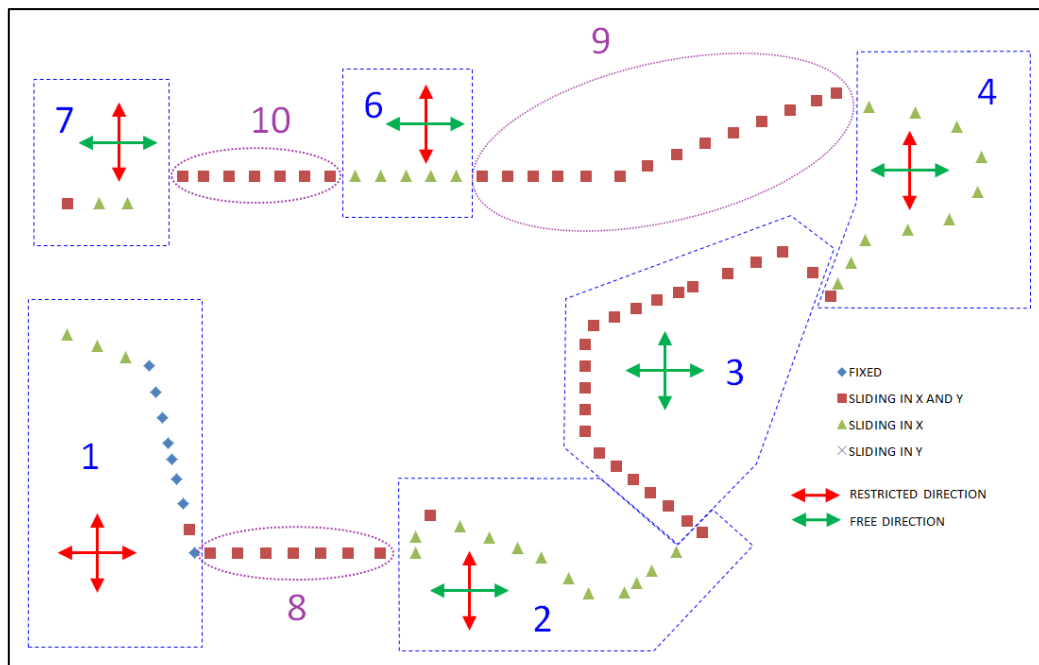


Figure 7: Supports configuration on the main gridshell [Lanik]

4. Final solution: special elastic supports

Although a great deal of different configurations was made, it became impossible to resist the loads and displacements with the projected structure without changing the height of certain beams between blocks 1 and 7, which would not be acceptable. Thereupon, special elastic supports were introduced.

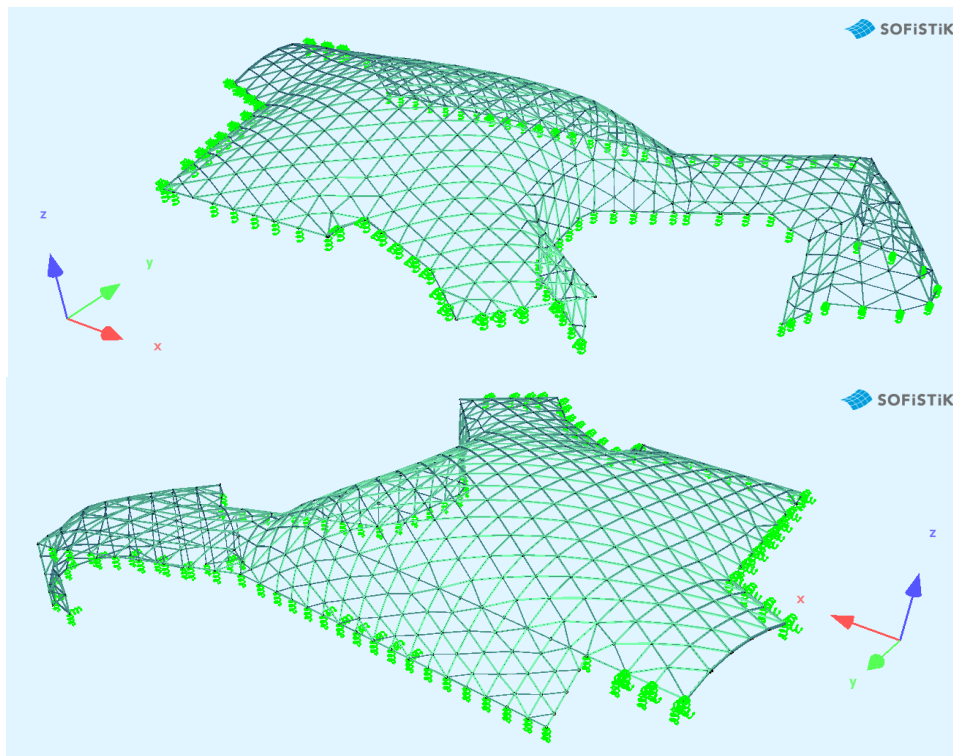


Figure 8: Sofistik model of the main gridshell. Notice the springs, which had the stiffness of each building [Lanik]

All the supports had been introduced previously in the model as springs, taking into account the actual stiffness of the building where they were attached (Figure 8). Block number 7 had 3 supports on it and their stiffness was changed in the model until the beam were under its limit.

In order to simulate the elastic supports, new springs were added between the structure and the block (Figure 9). If the stiffness of the set had been as high as the stiffness of the building, the node would have had larger reactions due to the displacements. On the contrary, with small stiffness, the structure would have resisted the large displacements but it would not have worked as a compression gridshell in that zone and would not have been able to resist the applied loads.

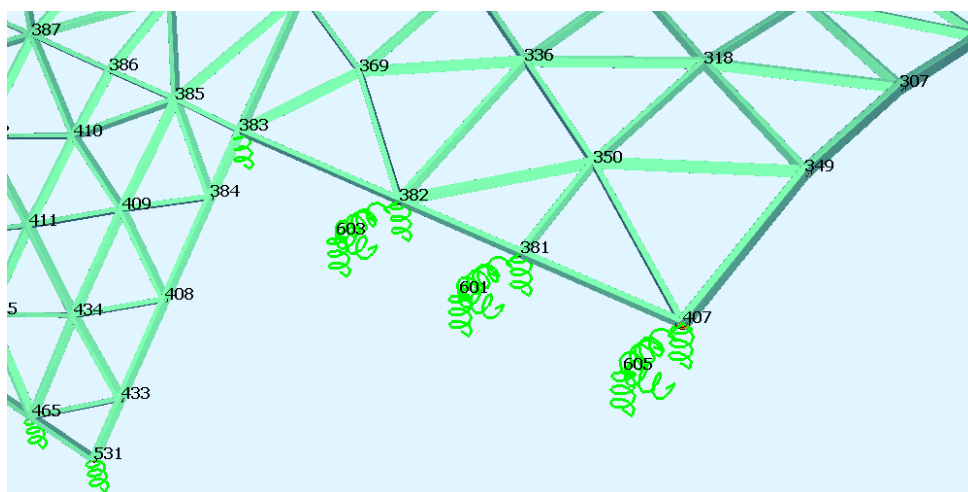


Figure 9: Elastic supports between the building and the structure [Lanik]

Several iterations were made until the most optimum stiffness for the supports in block 7 was reached. Finally, the obtained value was 3500 kN/m. With this exact stiffness, the structure would be able to allow the relative displacements between blocks 1 and 7 and to work as a compression shell to resist the applied loads at the same time.

SPRI	NO	284	NA	381	NE	601	CP	3500
SPRI	NO	286	NA	382	NE	603	CP	3500
SPRI	NO	287	NA	407	NE	605	CP	3500

Figure 10: Input lines in the Sofistik model for the aforementioned elastic supports [Lanik]

5. Description of the supports

After defining the required stiffness on the calculations, these properties had to be put into reality. Not only the elastic supports, but also some sliding supports had special demands since some had to allow displacements up to 120 mm. Besides, the wind created an uplift in some of those sliding supports, so they had to fulfil both requirements: vertical retention and displacements allowance.

The design of these special supports was based on Lanik's standards, but significant modifications had to be made.

5.1. Elastic supports

The main components of these supports are the springs. Their design had to take into account not only the required stiffness, but also other parameters like the allowable load or the maximum displacement.

Each support has 6 springs, 3 of them for each direction. When the structure moves in Y+ direction, only 3 springs are loaded; when it moves in Y- direction, the other 3 are loaded. The diameter and the total length of the springs was also a limit factor. They had to be small enough to fit in the space that had been set up on the roof.

Finally, these elastic supports had to be sliding in X direction and retain uplifting. As it is shown in Figure 11, under the node a PTFE plate and a stainless steel plate were disposed.

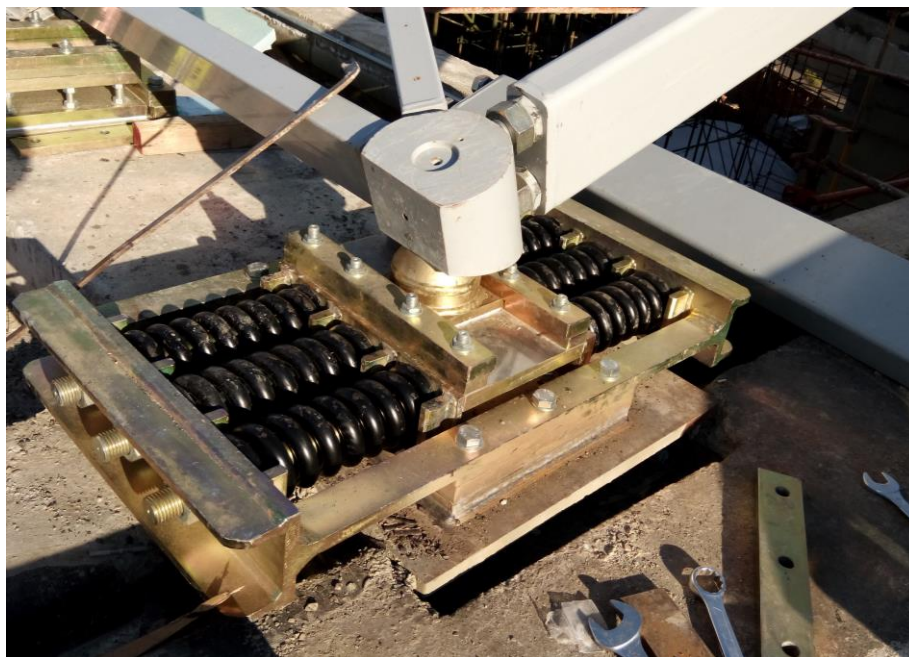


Figure 11: Elastic support in node 407 [Lanik]

5.2. Sliding supports for big displacements

The other group of special supports was the sliding ones. It is usual to use this type of supports on structures. However, the large relative displacements caused by the seismic hypotheses required a new design. Moreover, wind loads generated uplifting, so that certain supports had to retain the structure in the vertical direction.

These supports had to allow a horizontal displacement of 150 mm in both X and Y directions. Therefore, a system of guided plates was established in both directions, letting the node move as it was

calculated. As in the previous support, PTFE and stainless steel plates were used, in order to reduce the friction.



Figure 12: Special sliding support on site [Lanik]

6. Conclusion

Despite not having long spans and not being large compared to previous Lanik's projects, boundaries and loads conditioned strongly the structure. Common solutions could have been used, therefore those were proposed at initial stages. However, the requirements of the final client led to a deeper study and to the development of new solutions, turning the project into a significant engineering challenge.

References

- [1] J. Goñi and L. Irisarri, "Elastic-plastic behaviour of the SLO node for the second order calculation of the safety factor against global buckling in single layer structure", *IASS Symposium*, Wroclaw, Poland, 2013.
- [2] L. Irisarri, J. Martínez and J. Goñi, "Past, present and future of space frame Market: LANIK experience", *IASS Symposium*, Valencia, Spain, 2009.
- [3] M. Schlaich, U. Burkhardt, L. Irisarri and J. Goñi, "Palacio de Comunicaciones – a single layer glass grid shell over the courtyard of the future town hall of Madrid" , *IASS Symposium*, Valencia, Spain, 2009.