Full-scale test of glazing for stairs in theatre

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Keywords

1 = glass stair; 2 = distributed load; 3 = concentrated load; 4 = hard body impact; 5 = soft body impact

Abstract

The project of the Mariinsky theatre of Saint-Petersburg new building includes stairs with glass steps and balustrades. The audience passage could provide very large loads to theatrical stairs, so designers decided to carry out some full-scale tests of glass steps and side balustrades, which were produced according to design plans in full-size. Projects participants developed special test program taking into account safety rules acting both in Russia and in Europe. Tests were specific in conditions. Sizes, shapes and fastening of the samples were very different from described in standards for impact and deflection tests. That led to some new interesting results.

Introduction

In this work, we discuss the new special glass project, which includes theatrical stairs with glass steps and balustrades. During the test session we found that glass in the project are subject for the very high possible loads, but the good planning and right choice of the materials could provide outstanding performance of the building elements made of glass. However, we also found that testing of full-scale building elements could bring different results comparing to testing of standard samples.
Designers of the project decided to test elements of glass stairs for the highest possible load to show their adequacy to the project criteria. In parallel, designers used full-scale mockups to test various construction options more closely and accurately than it could be possible by computer modeling. We took part in the testing sessions and prepared official report for the project documentation package.

Test program

In this paper, we discussed mechanical loads tests. To be short let us just list test program sections, every section consist of test for at least three specimens:
1. Uniformly distributed load test
Uniformly distributed load of 6 kPa was applied to the specimen during 30 minutes.
2. Concentrated load test
6 kN was applied in the center of the specimen through the square nylon gasket and 100 mm side steel cube.
3. Glass step testing for the shock load by steel ball (EN356):
Basically, this is steel ball test with standard ball of 4.11 kg mass. Drop height was 3 meters; shock energy was 120 Joules. Tests had some special details in them:
a) Test started with first drop from 3 m height.
b) Upper layer of glass must be broken after that by hand if it was not broken by ball. After that, second and third drops were carried out.
c) After that the specimens were loaded by uniformly distributed load of 4 kPa during 30 minutes with deformation control.
d) And finally, the same specimens were loaded by the concentrated load of 4 kN in the middle of the specimen during 30 minutes with deformation control.
4. Glass barriers test for the shock load by soft body impact:
This is standard soft body impact test with rubber tires on metal core impactor. Soft body had mass of 50 kg and drop height was 1200 mm, so impact energy was 600 Joules. Detailed sequence was the following:
e) The specimen of the balustrade was tested by one soft body impact with 600 Joules of energy.
f) If the glass layers were unbroken after previous step, one glass layer was broken by hand and linear load of 1.5 kN/m applied the specimen without deflection control.
Acceptance criteria of the test results were usual standard for the described tests.
Hence, the test program corresponded with the following Russian standard test methods:
- For the balustrade barriers:

-- CM3-class testing to soft body impact stability;
-- Normative horizontal linear handrail loading test but with one layer of glass destroyed.
- For the glass steps:
-- Normative uniformly distributed load test with assurance factor equals to 1.5;
-- Concentrated vertical load test with 3 times more load comparing to normative requirements;
-- P2A-class hard body impact test;
-- Normative uniformly distributed load test and concentrated load test but with one layer of glass or more destroyed.
It worth to note that all tests includes supports which imitated real construction support system. Of cause, these supports are very different from standard test frames. Mostly, the specimens lay just clamped along short edges of the glass.

Description of the tested specimens

Specimens of the three types were tested:
- Laminated glass steps with heat-strengthened glass layers in the following composition: outside layer of 8 mm thickness, two intermediate 12-mm layers, inside 8-mm layer. Size of all such samples was 2000×400 mm. Glass layers were laminated with ionoplast polymer films. Specimens supported along two short sides. These specimens were marked “Step 8hs.12hs.12hs.8hs”. See Figure 1 for the mock-up with the installed specimen’s picture.
- Laminated glass steps with annealed glass layers in the following composition: 8-mm outside glass, two 15-mm intermediate layers and 8-mm inside glass. These specimens had the same sizes like listed above but during the tests, they were installed on the supports with 1700-mm wide gap to show real distance between the supports in the project of the stair. Laminated glass in this case included 1.52-mm-thick PVB foil. These specimens were marked “Step 8.15.15.8”.
- Laminated glass barrier, parallel shaped and consisted of two tempered glass layers, 12 mm thick each. Sizes were 1600 (length) × 1275 (height) mm, PVB foil was 1.52 mm thick. Installed specimens were supported by clamping along bottom edge. We marked these specimens as “Barrier 12t.12t”.

Figure 1. The stair mock-up with specimens installed: “Step 8.15.15.8” (lowest one), “Step 8hs.12hs.12hs.8hs” (other steps) and “Barrier 12t.12t” (barrier glazing).

Figure 2. The specimens marked «Step 8.15.15.8 № 1, 2, 3».

Despite some minor defects of the provided specimens, all of them we recognized as eligible for the tests.

The test results

Static load test results

All static load tests were carried out with the help of 15 liters volume sandbags and plywood panels. Total load for the concentrated load test was 600 kg; total load for the uniformly distributed load test was 480 kg. Concentrated load test also used steel cubes and plastic gaskets. Designers decided to start with concentrated load test, which is harder test than uniformly distributed test, and we agreed with that decision. Figure 3 consists of “Step 8hs.12hs.12hs.8hs” specimen’s photos on the moments of ending of load exposure time. All “Step 8hs.12hs.12hs.8hs” withstood the test without breakage. Maximum of the deflection in this test was 8.76 mm.

Figure 3. Concentrated load test for “Step 8hs.12hs.12hs.8hs № 1, 2 and 3” specimens.

When we applied concentrated load of 600 kg to the “Step 8.15.15.8 № 1”, it broke up after 23 minutes. The result repeated with “Step 8.15.15.8 № 3” after 25 minutes of load exposure. In both cases breakage started from 15-mm thick glass layer. Only “Step 8.15.15.8 № 2” withstood the test, maximum deflection was 18.90 mm which is much higher than we saw in the case of heat-strengthened samples with ionoplast lamination films.
Results of these test section you can see on Figure 4.

Figure 4. Concentrated load test for “Step 8.15.15.8 № 1 and 3” specimens.

There was no sense to test the same specimens for the concentrated load after two failures, so we proceeded to the uniformly distributed load test. Remaining three samples of “Step 8.15.15.8” withstood uniformly distributed load exposure during 30 minutes and maximum deflection was 6.60 mm.

Hard body impact test results

During hard body impact test we used already tested for static load specimens. Every specimen was hit three times by steel ball and uniformly distributed loaded by 4 kPa for 30 minutes after that.
Again all specimens “Step 8hs.12hs.12hs.8hs” withstood both stages. We noted that tests damaged only two outside layers of glass. Some results of this stage of test you can see on the photos from Figure 5.
It is worth to note that all tests showed that laminated glass with ionoplast films had relatively high bearing capacity even with some layers broken.

Figure 5. Some photos of hard body impact test for "Step 8hs.12hs.12hs.8hs" specimens.

Very different results were with "Step 8.15.15.8" specimens. Although they withstood ball hits, all of them were hardly damaged. Application of the smallest part of uniformly distributed load broke them finally as you can see on the Figure 6. Just one ball hit broke two glass layers in the "Step 8.15.15.8 № 2" and all 4 glass layers in the "Step 8.15.15.8 № 5".

Figure 6. Some photos of hard body impact test for "Step 8.15.15.8" specimens.

Soft body impact test results

Soft body impact test for barrier glazing included one soft body drop from 1200 mm height and application of 1.5 kN/m of linear load on the glass with one broken layer during 30 minutes. The linear load applied to the horizontally positioned specimen with clamping, which supplied the same force moment as in the case of linear load application to the handrail in project installation.
Tests were successful for all "Barrier 12t.12t" specimens, so nothing can be added here except the positive reaction to the right choice of the glazing construction. Some photos from this testing we include in Figure 7.

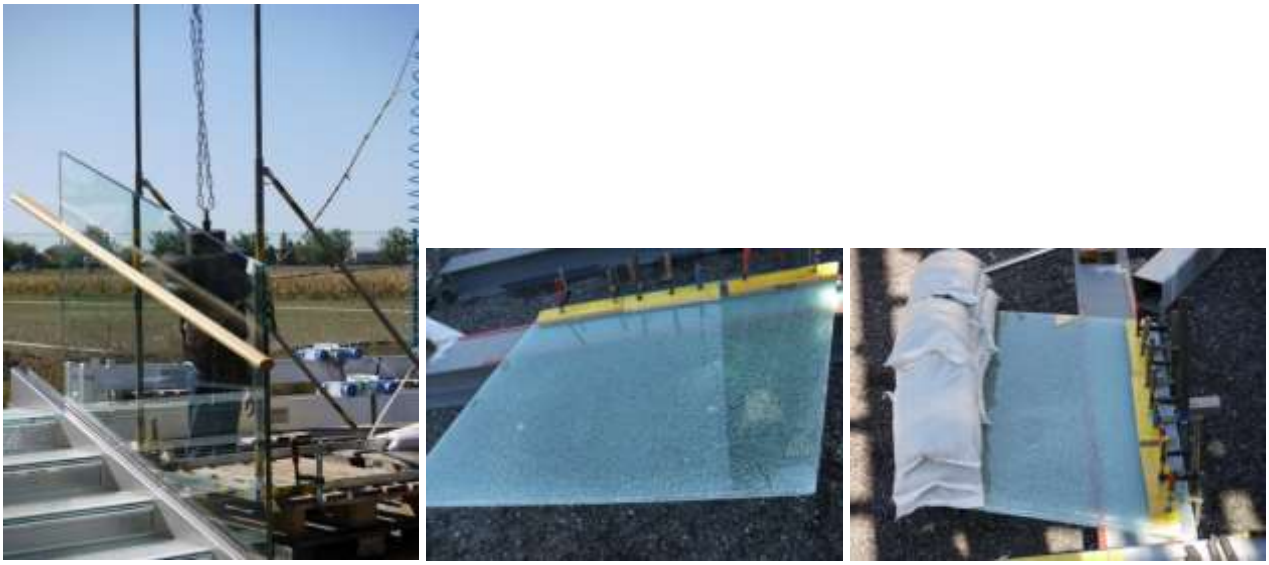

Figure 7. Tests of "Barrier 12t.12t" specimens for soft body impact and linear distributed load.

Conclusions

All specimens of “Step 8hs.12hs.12hs.8hs” showed good performance and passed all tests without serious comments. It worth to mark that the average deflection under concentrated load of 600 kg was 8.21 mm which very close to the recommended deflection of 8.00 mm. Nevertheless, our recommendation refers to uniformly distributed load.
Ionoplast lamination films showed very good stability and stiffness comparing to PVB films.
Specimens of “Step 8.15.15.8” did not pass the tests. However, their average deflection under uniformly distributed load was lower than recommended deflection: 6.40 mm comparing to 6.80 mm. In addition, we marked that deflection was increasing all time specimen during load exposure. It is possible, that float glass step could pass the tests if laminated glass included more stiff films than usual PVB.
All specimens of “Barrier 12t.12t” passed their tests very successfully despite the one-side support.

References

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