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A PRECAST REINFORCED CONCRETE SYSTEM WITH CONTROLLED DYNAMIC PROPERTIES

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The precast reinforced concrete system with controlled dynamic characteristics allows, together with demountability, an efficient optimization of a load-bearing system's response to external dynamic and static loading effects and impacts. The essential elements of the system are the joints of load-bearing reinforced concrete precast units with high ductility allowing the absorption of dynamic energy and the optimization of the load-bearing system's response to technical as well as natural seismicity. Another significant feature of such joints is their ability to eliminate outside noise (e.g., traffic, building activity, industrial activity) below the threshold of hearing; this improves the quality of the interior environment and allows land development in areas with increased noise levels, traffic, etc. The system may also be analogically applied in areas with poorer foundation conditions, in areas with underground traffic, in undermined areas, and in areas with high seismic risks.

Keywords: Precast, Concrete, Demountability, Seismicity, Absorption.

1 INTRODUCTION

Precast reinforced concrete construction systems for multi-story buildings with controlled static and dynamic properties require special components. A characteristic component is demountable joints of load-bearing precast reinforced concrete units with high ductility, able to absorb strain energy, which limit the intensity of particularly dynamic and cyclic effects to a level that will not cause a failure of the building or its parts. These joints also reduce outside noise (e.g., traffic, building activity, industrial activity) below the threshold of hearing, thus enhancing the quality of the inside environment, allowing development in zones with increased noise emissions due to traffic, etc. The system may be applied analogically in areas with substandard foundation conditions, in areas with underground traffic, in undermined areas, and in earthquake areas. Demountability also allows for new spatial layouts over time depending on the current user's requirements – i.e., a building may be made bigger or smaller, gradually completed, used for a different purpose, etc.

2 STRUCTURAL DESIGN SOLUTION OF DEMOUNTABLE JOINTS

A demountable "column–girder" joint consists of a) steel plate anchors and steel mounting plates embedded in a precast column, and b) girder and connecting steel elements additionally mounted during the assembly. The connecting steel elements are immovably fixed, by means of a screw joint or a special lock joint, into plate anchors embedded in columns, which form short cantilevers onto which girders are subsequently mounted by means of steel mounting plates (Fig. 1).

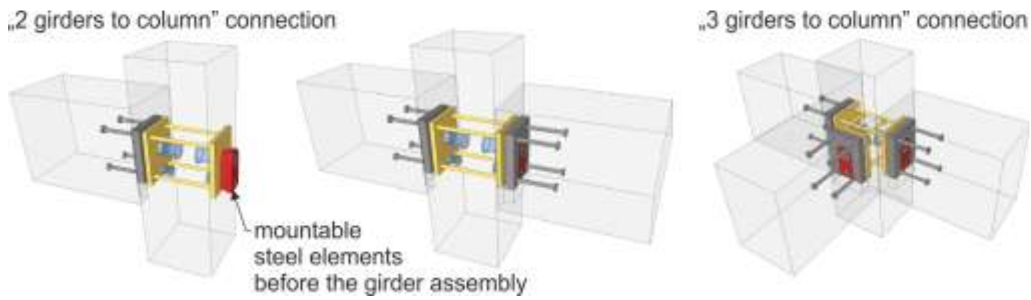

Figure 1. Connection of columns and girders.

The "column–column" joint is designed on the principle of adjusting screws fitted with mounting and, simultaneously, with leveling nuts for the leveling and plumbing of the upper-story column into the required height and vertical position.

The height-leveled screws and anchor pins projecting from the column head of a lower story are used for mounting a load-distributing steel plate. This is then fitted with a rubber bearing with the required stiffness. Thus vibrations of certain frequencies are damped, or the dynamic properties of the load-bearing column system are modified in a desired way (Fig. 2).

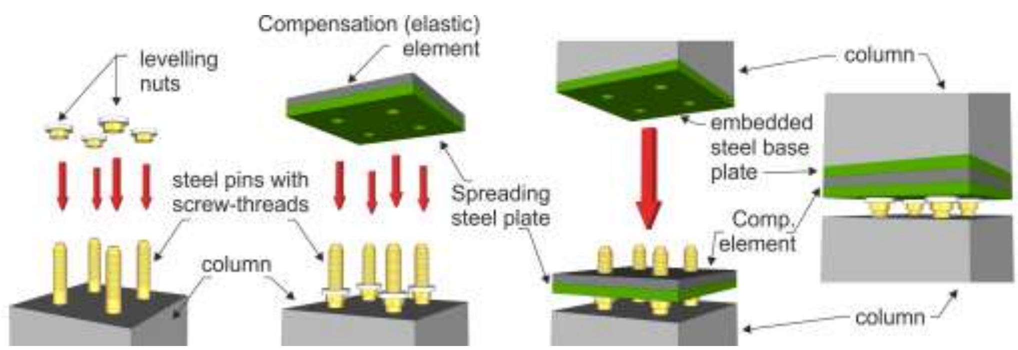

Figure 2. Column-to-column connection with leveling possibilities.

3 CONTROLLED DYNAMIC PROPERTIES

Research into seismic loads and buildings' responses to the effects of natural, technical and induced seismicity is currently an intense subject of worldwide research. This is with respect to buildings situated in zones of higher natural seismic activity, buildings suffering from growing traffic volumes and growing construction volumes (both overground and underground), and buildings affected by technical and induced seismicity. A high sensitivity of precast-reinforced concrete increases the risks of the structural performance failure of load-bearing systems exposed to long-term intensive vibrations, shocks, or seismic effects. This is primarily true for wall or column systems of multi-story buildings with "rigid" joints (i.e., with low ductility – a low domain of elastoplastic deformations), which are particularly susceptible to the effects of induced deformations, strains and vibrations (Witzany *et al.* 2009).

A characteristic feature of load-bearing systems that contain joints with controlled properties is their ability to absorb certain amounts of strain energy due to exceptional loads, natural seismicity, or long-term cyclic variable-loading effects. The reduced stiffness and increased ductility of the joints is reached by mounting elastic components in the area of their mutual contact, and by removing grouts. The stiffness/ductility of this elastic component must be determined with respect to the structural demands of the loads, the effects carried by jointed units, and the demand for damping vibrations and dynamic effects of certain characteristics (Witzany *et al.* 2013). For example, traffic-induced technical seismicity differs from natural seismicity in terms of higher frequencies from the surroundings, and in terms of frequent repetitions which may exceed material fatigue limits. The frequencies of traffic-induced vibrations range from 10 to 200 cycles/sec (most frequently 30 to 150 cycles/sec), while the amplitudes of these vibrations are low, reaching no more than several tens of micrometers. Natural seismicity has roughly 100 times lower vibration frequencies, while the amplitudes of vibrations are higher by several orders. The acceleration of traffic-induced vibrations corresponds to the values of catastrophic earthquakes with magnitudes of 10 to 12 on the Richter Scale. Road traffic-induced vibrations propagating into neighboring built-up areas usually reach dominant frequencies ranging roughly from 5 to 25 Hz. Vibrations due to surface rail traffic (trams, railway trains) have dominant vibrations of roughly 5 Hz to 50 Hz (Makovička and Makovička 2011).

4 STRUCTURAL DESIGN SOLUTION OF THE LOAD-BEARING SYSTEM

The spatial stability of an articulated precast column system is secured in two ways: 1) by precast reinforced-concrete diaphragms or stiffening steel structures (e.g., A-shaped); 2) by special stiffening structures (steel cables or pipes bracing diagonally the pin joints of columns and girders) embedded in some "frame" bays. In the case of a unidirectional arrangement of "frames", this system is secured between columns perpendicular to the frame bay.

If articulated frames are stiffened by embedded thin-walled reinforced concrete diaphragms, the columns and girders are mutually discretely connected with the diaphragms by means of contact rubber bearings. The distribution and stiffness of these bearings depend on the magnitude and intensity of the static or dynamic loads. The essential factor affecting the dynamic characteristics of an articulated column system is primarily the shear stiffness, or the number and distribution of rubber bearings (Fig. 3 and Fig. 4).

Figure 5 displays the dependence of natural frequencies of a simple articulated frame with embedded diaphragms on the stiffness of contact rubber bearings. It also displays the dependence of the deflection on the upper free end of an articulated frame due to the effect of horizontal loading.

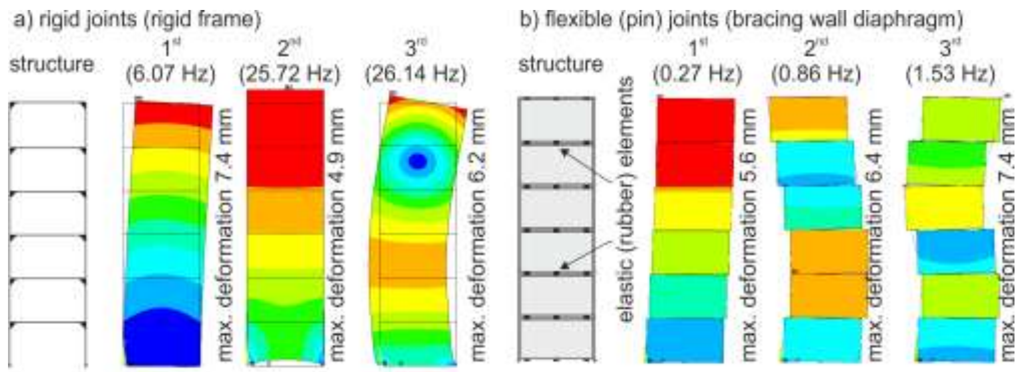

Figure 3. Comparison of natural frequencies of a rigid frame and an articulated frame with stiffening diaphragms and contact rubber bearings (E = 3 MPa).

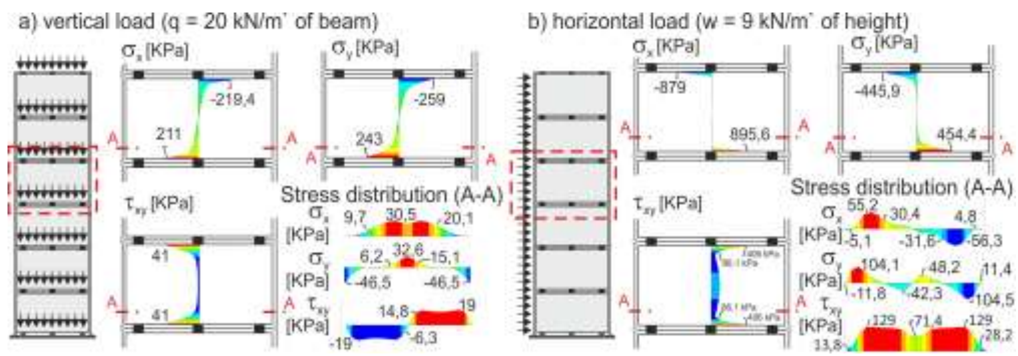

Figure 4. Stress distribution in bracing diaphragm for vertical and horizontal loads.

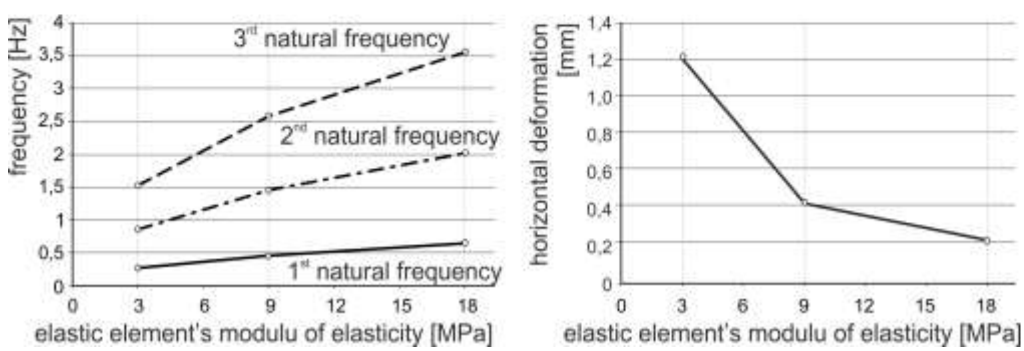

Figure 5. Dependence of natural frequencies on the stiffness of contact rubber bearings.

5 STATIC, DYNAMIC AND FIRE-RESISTANCE VERIFICATION TESTS

The designed solution of a precast-column system was subjected to experimental static tests, and partially to the dynamic testing programme (Fig. 6 and Fig. 7).

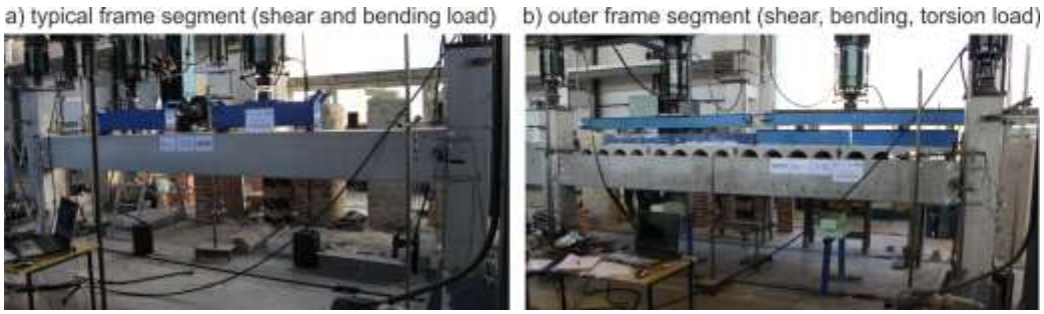

Figure 6. Setup of experimental static tests (typical and outer frames).

Figure 7. Failure of tested structure after static loading.

The objective of these tests is to verify the dynamic properties of a segment of an articulated "frame" structure composed of two columns, two girders, and an embedded reinforced concrete diaphragm 80 mm in thickness. This is connected to the columns and girders by means of contact rubber bearings.

A segment of the structure, composed of sections of columns and short sections of girders, served as the fire resistance test of demountable "column–column" and "column–girder" joints. The fire safety of joints was designed using glued-in foam strips (Fig. 8).

The test configuration for the static verification of the load-bearing system was used for the technological verification of the characteristic configuration of a load-bearing system. It was composed of columns and a girder-repetitive assembly and demounting of the configuration, including the verification of designed joints in terms of requirements for production and assembly tolerances.

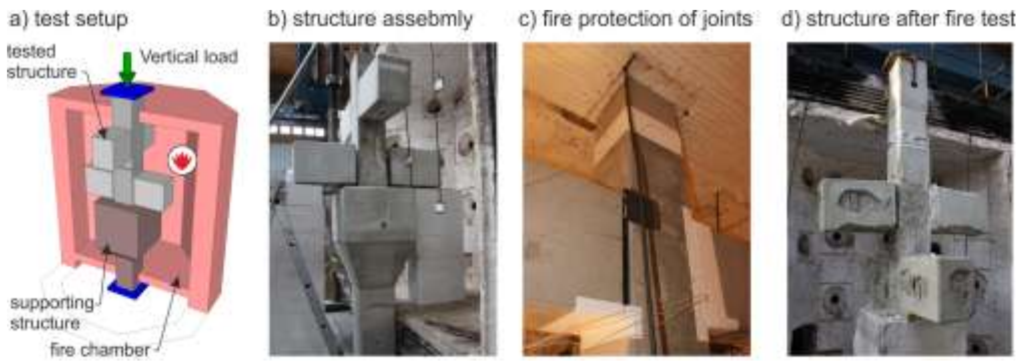

Figure 8. The fire resistance test of demountable "column–column" and "column–girder" joints.

6 CONCLUSIONS

The static tests carried out on characteristic configurations of a load-bearing structure and its joints manifested the required parameters of the designed solution – i.e., its load-bearing capacity and serviceability. The vertical load of the test configuration was recalculated for a field of 6 x 9 m. The "column–girder" joint and the reinforced concrete girder failed under loading amounting to 19 kN/m2 (test configuration A), or 22 kN/m2 (test configuration B) of recalculated load (Fig. 7).

The technological test manifested the possibility of repetitive collision-free assembly and demounting without any damage to anchoring and connecting steel elements and the load-bearing reinforced concrete units (Fig. 6).

The fire resistance test resulted in the failure of the concrete (gradual concrete disintegration) at a temperature of 1000°C after 90 minutes. The anchoring steel and connecting elements showed no signs of failure that might be the cause of a subsequent collapse of the joint and the structure after the completion of the fire resistance test (Fig. 8d).

Acknowledgments

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