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NUMERICAL SIMULATIONS ON A FATIGUE TESTING FACILITY

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Abstract
Dynamic fatigue tests are used to evaluate the fatigue behaviour of material and structures. The Institute for Structural Engineering has developed a new method for dynamic fatigue tests on large specimens like stay cables. This method makes it possible to increase the testing frequency up to 50 Hz. After tensioning the specimen and the auxiliary cable an unbalanced vibration generator applies the vibration loading. In case the testing frequency of the specimen is equal to the first eigenvalue of the testing setup the applied load of the vibration generator is multiplied depending on the damping of the system. For example, if damping is 0,5 % the vibration generator has to apply only one hundredth of the required stress range. So the novel fatigue testing facility requires less time and a lower demand of energy than conventional servo hydraulic controlled testing units.

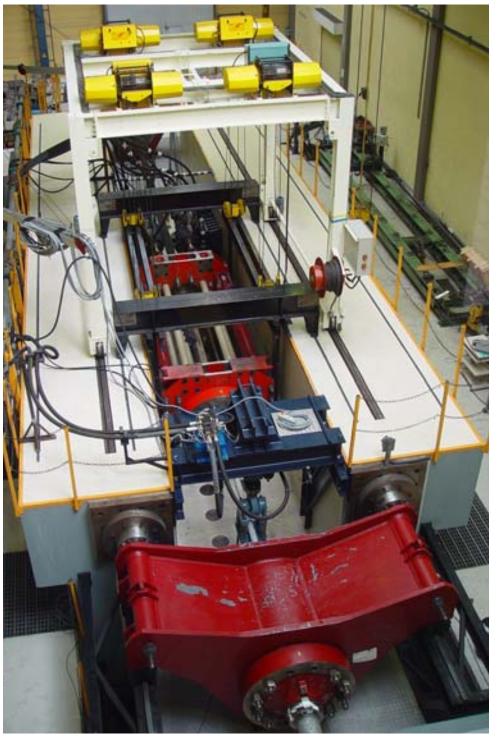
INTRODUCTION

In case of dynamic load structures can collapse even in case when the applied load is much lower than the ultimate limit static load. So the knowledge of the fatigue behaviour of different building materials is very important for the durability of structures.

For instance, dynamic fatigue tests are carried out to evaluate the fatigue limit of stay cables, tendons, couplings of tendons and anchorages of cables and tendons. The PTI-Recommendations for stay cable design, testing and installation regulate the test procedure for stay cables.

In Europe three accredited testing laboratories are able to do dynamic fatigue tests on big specimen as stay cables or tendons up to 55 stranded wires. The laboratories at the University of Technology in Munich as well as at the EMPA (Eidgenössische Material- und Prüfungsanstalt, Dübendorf, Switzerland) apply the upper load and the cycling load by means of a servo hydraulic controlled jack. On the one hand the testing setup is very simple but on the other hand the testing frequency is low (max. 1Hz), because each loading requires applying the total upper load. So a fatigue test with two million load cycles takes 23 days. Furthermore, a lot of energy is needed to cool down the hydraulic oil of the aggregate.

The LCPC (Laboratoire Central des Pontes et Chaussêes) is a national organization for applied research and development near Nantes. Operational since 1989 at the Nantes Testing Center, this device (Figure 2) allows conducting fatigue resistance tests on cables and anchorages of prestressed concrete bridges, cable-stayed or suspension bridges and offshore platforms.



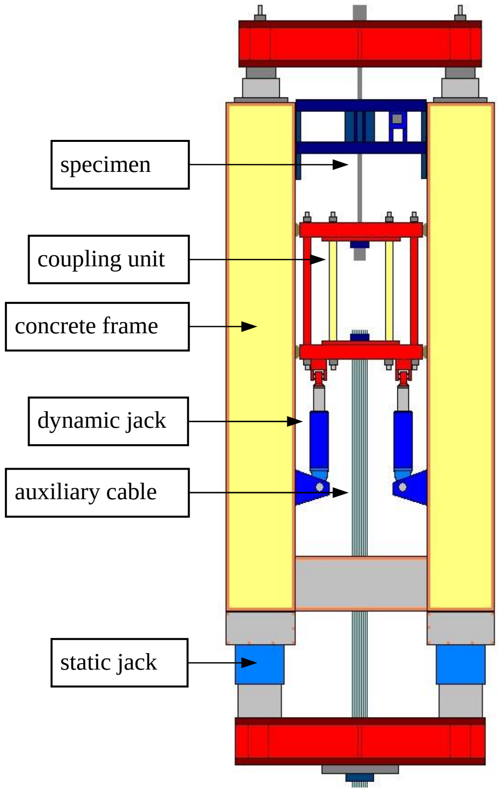


Figure 1 - Overview of the fatigue testing bench [2]

First the cable and its anchorages are placed into so-called "static" tension and then a "dynamic" force variation is applied. By means of an auxiliary cable, a coupling unit and a static hydraulic jack the specimen is tensioned. The dynamic force is applied with the aid of smaller dynamic jacks. Because of the dynamic jacks each cycle requires only applying the dynamic stress range and so the achievable testing frequency is around 1.5 Hz and therefore higher than at the devices in Munich or at EMPA.

DEVELOPMENT OF A FATIGUE TESTING FACILITY AT THE INSTITUTE FOR STRUCTURAL ENGINEERING

The Institute for Structural Engineering at Vienna University of Technology has developed a novel fatigue testing facility with testing frequencies from 25 to 50 Hz. A survey of the Austrian patent office approved the capability of the development [1]. The Vienna University of Technology applied for a patent in April 2005.

Considering the high testing frequency the novel fatigue testing facility requires only a fractional amount of the energy which is needed by conventional facilities to carry out a test with two million load cycles. The dynamic load is applied via an unbalanced vibration generator and so no energy to cool down the hydraulic oil during the test is necessary. Due to the high testing frequency e. g. 25 Hz the time for two million load cycles decreases to 23 hours.

Effectiveness of the facility

In Figure 2 the testing setup is shown schematically. The specimen (e. g. a stay cable) and the auxiliary cable are tensioned with the aid of a static hydraulic jack. This static jack applies the basic load for the following fatigue test. An unbalanced vibration generator, which is placed at a coupling unit between auxiliary cable and specimen, applies a harmonic load in axial direction. The coupling unit is used to connect the auxiliary cable and the specimen to carry the vibration generator and to fix optional added mass, which is needed to regulate the eigenvalue of the testing setup.

The stiffness of the testing frame has to be high, compared to the stiffness of the specimen and the auxiliary cable. If this condition is fulfilled the setup can simply be described as a single degree of freedom system. The eigenvalue (ω) and the natural frequency (f) of the system can be determined easily.

$$\omega = \sqrt{\frac{K}{M}} \tag{1}$$

$$f = \frac{\omega}{2 \cdot \pi} \tag{2}$$

$$K = K_{Auxil.} + K_{Specimen} \tag{3}$$

The eigenvalue and the natural frequency respectively are depending on the stiffness of the specimen and the auxiliary cable as well as on the mass of the coupling unit. Variation of the stiffness of the auxiliary cable and of the mass at the coupling unit can regulate the eigenvalue of the testing setup. If the rational frequency of the unbalanced vibration generator, which can be adjusted by a frequency converter, is equal to the eigenfrequency of the setup the applied load is multiplied due to resonance. The dynamic enlargement factor (V_{Dyn}) depends on the damping (ξ) of the structure as well as on the damping of the used materials.

$$V_{Dyn} = \frac{1}{2 \cdot \xi} \tag{4}$$

In order to get a high dynamic enlargement factor the damping has to be low. For example, if overall damping is 0,5 % the dynamic enlargement factor amounts to 100. So the vibration generator has to apply only a range of 1 kN to reach a range of 100 kN in the specimen in case the system is in resonance.

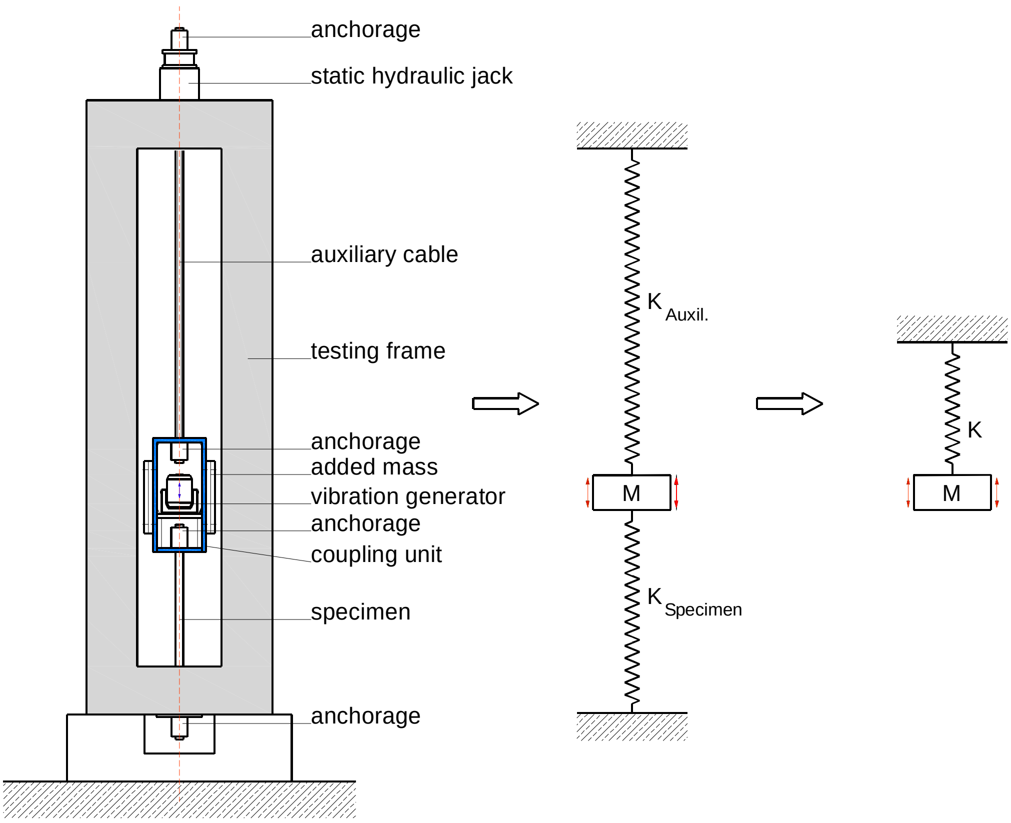


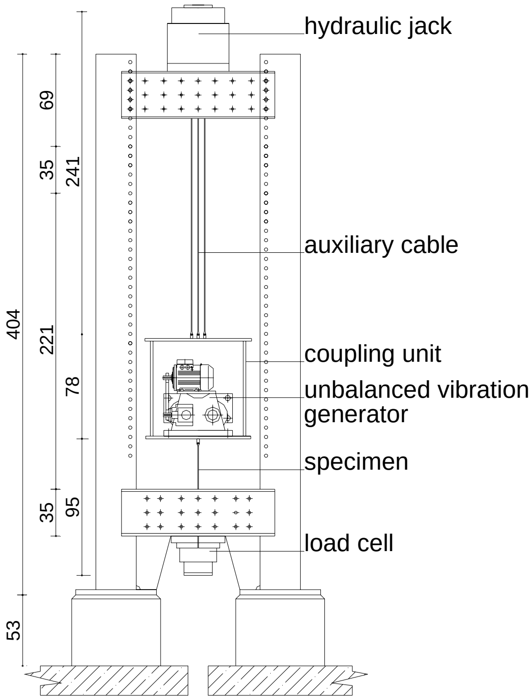
Figure 2 - Fatigue testing facility and one degree of freedom model

Preliminary tests on a horizontal and a vertical testing facility

In the laboratory of the Institute for Structural Engineering preliminary tests on a vertical and a horizontal testing facility were carried out. These tests proved that the testing method can be used in practice.

Vertical and horizontal testing facility

A vertical testing facility was realized at a vertical steel frame, shown in Figure 3 (left) in the laboratory of the institute. For the specimen a tension rod with a diameter of 8 mm and for the auxiliary cable three tension rods with diameter of 6 mm were used. The static loading was applied with a hydraulic jack at the upper crosshead of the steel frame. On the lower crosshead a load cell was installed at the anchorage in order to measure the force in the specimen. At the auxiliary cable as well as at the specimen strain gauges, two at each rod were applied to measure the strain and thereby the force in the rods. At the coupling unit, a frame made of steel, three acceleration sensors were applied to measure the acceleration and thereby the movement of the coupling unit.



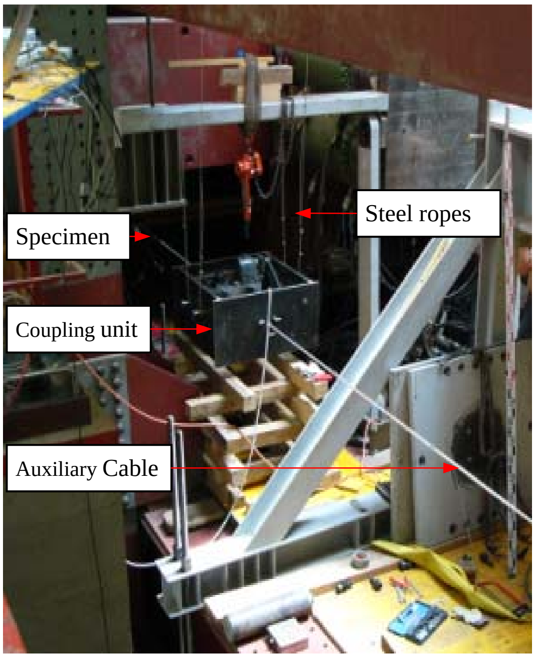


Figure 3 - Vertical (left) and horizontal (right) testing arrangement

The dynamic load was applied with the aid of an unbalanced vibration generator, courtesy of “arsenal research”, Vienna. Different unbalanced weights of the generator made it possible to vary the stress range of the specimen. By means of fixing additional mass at the coupling unit it was possible to change the natural frequency of the testing arrangement. The rotational frequency of the vibration generator was controlled by a frequency converter, so each designated eigenvalue could be adjusted.

The horizontal facility was different to the vertical set-up in a few points. It was implemented at a big horizontal testing unit in the laboratory of the institute. To maintain the movement of the coupling unit in axial direction four steel ropes were used, as can be seen in Figure 3 (right). They were fixed at the coupling unit and at a crosshead of the big testing unit. The lengths of the specimen and the auxiliary cable were determined by the dimensions of the big testing unit. In order to vary the stiffness of the auxiliary cable two different rods were used.

Results from the dynamic test and numerical simulations

For both arrangements an extensive test program was carried out. The influence of variation of the added mass as well as variation of the stiffness of the auxiliary cable (only at the horizontal facility) was researched. The expected eigenvalues and stress ranges of the arrangement were determined by analytical calculations of a single degree of freedom system as well as by numerical finite element analyses. Later the results were compared to the measured values during testing. The correlation of the measured and calculated eigenvalue was quite good. In Figure 5 the mode of the testing facility at a frequency of 34,34 Hz is shown. The measured eigenfrequency of this arrangement was 33,71 Hz. A detailed compilation of the results can be found in the Master's Thesis of Maier [3].

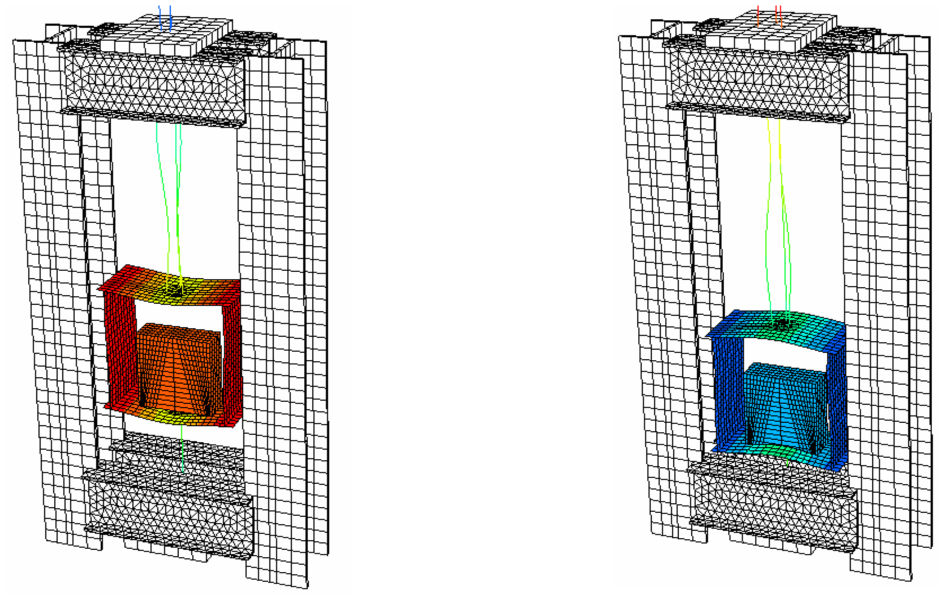


Figure 4 - Calculated eigenmode of the vertical facility, maximum deflection (left) and minimal deflection (right)

The peaks in Figure 5 clearly show the eigenfrequency of the testing arrangement for two different tests. As expected additional mass at the coupling unit is leading to a reduction of the eigenfrequency. The similar effect could be noticed if the stiffness of the auxiliary cable was reduced. This could be achieved for example by reducing the diameter of the auxiliary cable. The unbalanced mass of the vibration generator had been the same for both tests, so this is the reason why the acceleration at the frequency 19,4 Hz was higher than the one at the frequency 16,3 Hz. The applied load of the vibration generator depends on the unbalanced mass and on the number of revolutions, so a lower eigenfrequency of the setup requires a lower rotational frequency of the unbalanced vibration generator and therefore a lower load.

The applied force of the vibration generator is split up proportionally to the stiffness of the specimen and the auxiliary cable. Figure 6 shows, in case of a horizontal testing setup, the numerical determined axial forces of the specimen and the auxiliary cable. The ratio of forces and their amplitude as well as the damping behaviour of the setup is more or less equal to the measured values. The dynamic enlargement factor is about 113, the value determined during testing was, depending on the testing setup in a range from 95 to 114,5.

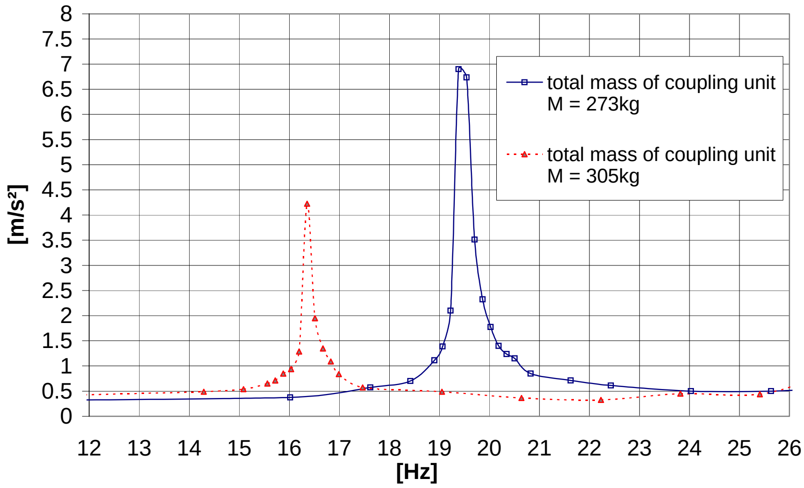


Figure 5 - Acceleration in axial direction for different testing arrangements

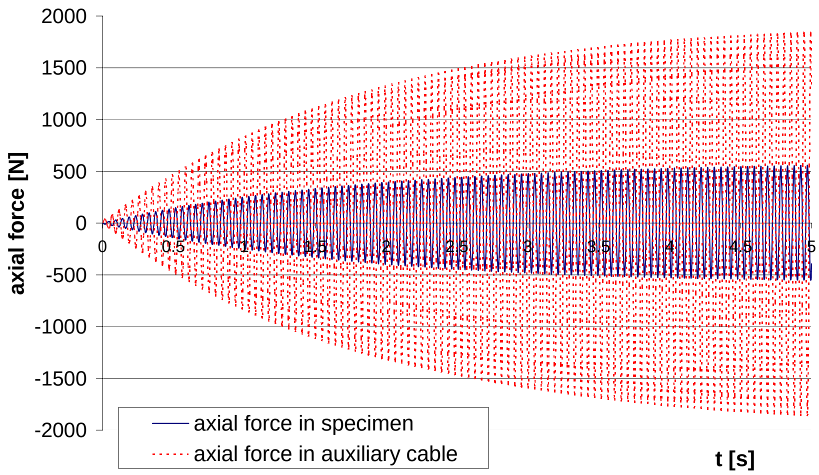


Figure 6 - Axial forcAcceleration in axial direction for different testing arrangements

CONCLUSION

Due to the promising results of the preliminary tests and the support of Vienna University of Technology a novel testing facility for large specimens is presently being built in the laboratory of the Institute for Structural Engineering.

This testing unit (a prestressed concrete frame) should enable the scientists to carry out dynamic fatigue test with an energy requirement lower than the existing devices. The new testing method will decrease the duration for fatigue tests dramatically and fatigue tests can be carried out more economically in the future. The testing unit will be dimensioned for a static tensile load up to 20.000 kN, an upper load for fatigue tests up to 10.000 kN and a vibration range up to 2.500 kN.

The laboratory is located in downtown Vienna, therefore the high testing frequency and the generated high free massforce, it is very important to avoid disadvantageous effects to adjacent buildings. To avoid such effects numerical simulations were carried out at the Institute. The problem will be solved by a special adjustment of the bearing from the testing unit. Figure 6 shows the displacement of the coupling unit compared to the movement of the testing frame. If the displacement of the frame is known the reaction force, which is prefaced into the ground, can easily be determined by the spring stiffness of the bearing (springs made of steel). Due to this adjustment the prefaced forces into the ground are quite low. For example, if the testing frequency is 50 Hz and the eigenfrequency of the bearing is 2 Hz only, 0.16 % of the free mass will be induced to the foundation of the testing frame

Figure 5 Calculated eigenmode of the vertical facility

The new testing facility will offer additional and new cooperation with industrial partners. Also scientific research on fatigue behaviour of different building materials will be carried out at Vienna University of Technology.

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[3] Maier Ch., *Entwicklung einer Prüfvorrichtung für Dauerschwingversuche mit*