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APPLICATION OF STEEL SPRINGS IN THE SUPPORT OF BUILDINGS

HG Wagner GERB Vibration Control Systems / Germany

1. INTRODUCTION

The protection of people, buildings and equipment from disturbing or damaging mechanical vibrations has become more and more a world-wide challenge. Modern traffic systems have to keep up with the fast growth of cities and global business and the general mobility of people. Nowadays, new underground lines or other commuter systems at street level or elevated are being planned or under construction in many cities all over the world. High-speed trains make travel times shorter competing even with aircraft. However, for quite a number of people they are a nightmare, as noise and vibration problems increase rapidly making people complain.

The vibrations radiating from rail tracks cover a wide zone along the tracks and impair the value of many precious building sites in the cities and suburbs. Especially in the town centres where rail tracks cumulate near the stations many plots are hit by vibrations. These plots of land could otherwise be used for public facilities like hospitals, theatres, concert halls, museums and hotels but also residential houses. In such cases it is always worth spending an extra amount on reliable measures to counteract noise and vibrations. Many neglected building plots could be upgraded thus improving the quality of the whole area.

Today anti-vibration measures are applied either directly to the trackbeds in a most effective way by means of so-called mass-spring-systems or directly under the buildings. GERB Vibration Control Systems, a German company operating world-wide, has specialised for many years in the design, manufacture and installation of elastic spring systems for both applications.

While air-borne noise requires its own specific counteractive measures, ground-borne vibrations and structure-borne noise can best be dealt with by elastic bearing systems to provide successful protection of buildings. They have been used for decades for vibration isolation by decoupling buildings and other structures dynamically from their foundations thus avoiding the transmission of vibrations.

2. SUMMARY

For about a century helical steel springs have been successfully used for vibration isolation. Their typical characteristics like linear load/deflection curve, wide elasticity range at high loads, and adequate horizontal stiffnesses make them an ideal tool for applications in both the low and the high frequency range. More than 80 buildings of all kinds and sizes have been effectively supported on spring elements containing steel coil springs to counteract perceptible low-frequency vibration excitations and structure-borne noise caused by nearby traffic or industry.

After initial references to the special characteristics of helical springs this paper shows the different kinds of steel spring elements and how they are used in the support of buildings. Examples in Germany and the UK are presented to illustrate this exciting up-to-date technique contributing to the improvement of the environmental circumstances.

3. HELICAL STEEL SPRINGS

Today, there are several kinds of anti-vibration systems available. Consulting and structural engineers are in a position to select from a variety of bearing systems of different materials, shapes and capacities in an effort to provide the best solutions.

In many cases helical steel springs have proved to be the best choice in terms of reliability, efficiency and safety. Their specific characteristics make them ideal to attenuate both low and high frequency vibrations, i.e. vibrations you can feel and vibrations you can hear. Reductions of 20 - 25 dB can be expected.

The favourable spring characteristics are:

- **High elasticity**

Steel springs are most economical at static compression levels between 5 and 250 mm, or, if put in dynamic terms, at vertical natural frequencies between 7 and 1 Hz. They are especially effective when the situation demands real vibration isolation. That means that they provide high isolation efficiency even at very low frequency excitations, e.g. between 5 and 15 Hz.

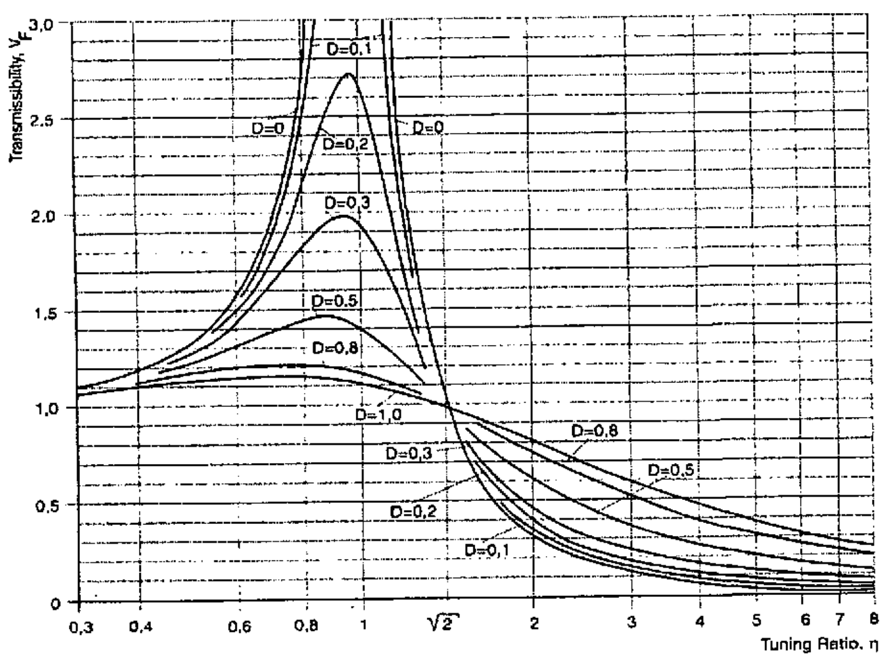

Fig.1 Transmissibility curves

The diagram shows the transmissibility factor versus the tuning ratio. The tuning ratio is the ratio of the frequency of an excitation source to the natural frequency of a mass-spring-system.

The curves show that if the ratio is beyond the value of $\sqrt{2}$ only then does the transmitted dynamic force becomes less than the exciting force. Only in this case does spring support result in vibration isolation. It is obvious that it is the particular elasticity of a spring that makes all the difference.

Example for an undamped system at harmonic excitation:

excitation frequency = 12 Hz
system natural frequency = 3.5 Hz
tuning ratio = 3.4
isolation efficiency = 90.5 % or 20 dB

- **Linear load deflection curve**
  The linear relationship between load and spring deflection makes a spring system easy to calculate. There is no change of stiffness resulting from changing loads.

- **No difference in static and dynamic stiffness**
  Both the static and the dynamic stiffness are the same.

- **High load capacities**
  Steel springs can be designed to take high loads.

- **Defined vertical and horizontal stiffnesses**
  The spring stiffnesses can be clearly determined by calculation. The horizontal stiffness can be designed higher, same or lower than the vertical one, as required. By taking horizontal loads as well there is no need for the additional arrangement of horizontal restraints in a spring supported system.

- **Long lifetime**
  A steel spring when properly designed and used does not suffer ageing or fatigue. Its lifetime is almost unlimited. There is no time-dependent change in the characteristics and especially in the stiffnesses. High-quality coatings are available to prevent corrosion.

4. SPRING ELEMENTS

Steel springs when used under buildings are usually arranged in packages or so-called spring elements. The load capacity of an element at a certain spring deflection depends on number and type of the springs contained in the element. By reducing or increasing the spring number the load capacity can be gradually adjusted to the outer load. Spring elements are available with load capacities matching with every load from some kN up to 2000 kN at a given spring deflection. The spring deflection which defines the efficiency of the system is governed by choice of a spring type of suitable stiffness.

GERB Vibration Control Systems offers 3 basic types of spring elements to be used in buildings. Their difference is only in the element housings which sandwich the springs. There is no difference in the type and quality of the springs themselves respectively in the dynamic or static efficiency.

4.1 Non-Prestressible Spring Elements

Non-prestressible spring elements consist of springs simply arranged between 2 steel plates. The elements can be distributed over the surface of a supporting structure like elastic pads as required. The design deflections occur gradually with the increase of the building loads.

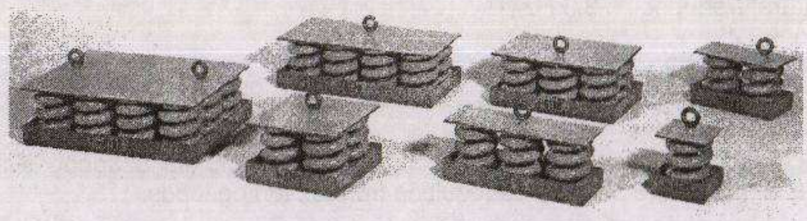

Fig. 2 Non-prestressible spring elements

Once the building is completed it is hardly possible to carry out any change or correction. Therefore it is important that the design loads are most accurately determined to avoid under- or overloading of the springs. These spring elements are suitable for use under buildings of a relatively simple structure with clearly definable loads and where the loads can be built up uniformly. The main advantages are in the low space requirement and in the price.

4.2 Partly-Prestressible Spring Elements

This kind of element has reinforced steel plates (housings). The higher stiffness of the structure enables the pre-compression of the elements to a certain static spring deflection prior to placement on the substructure. Elements pre-loaded in this manner take the increasing construction loads without giving in thus making building work easier.

Fig. 3 Partly-prestressible spring element

After completion of the building the spring heights can be measured when appropriate access areas have been prepared. Deviations from the design deflection values can be corrected by shimming up to a certain limit. With some effort it is even possible to shift or to remove an element as required.

4.3 Fully-Prestressible Spring Elements

These elements possess housings designed to be stiff enough to take the full pre-compression of the springs down to solid spring height if this is required.

Fig. 4 Fully-prestressible spring element

Again, these spring elements when built-in already precompressed to the operational loads, serve like rigid bearings during construction without giving in. Later, they provide all possibilities for height adjustment, shifting, swapping and replacement when required under the completed building. This way they ensure that the vibration isolation system finally will do the job it is designed for. That makes them most recommendable especially for large and complex buildings where the determination of loads which will actually occur may be difficult.

5. EXAMPLES OF BUILDINGS ON STEEL SPRINGS

5.1 Office Building on Non-Prestressible Spring Elements

In the German capital Berlin a 6-storey office building was to be built sandwiched between 2 existing houses right over a diagonal crossing underground track with 2 neighbouring single-track tunnels. The upper edge of the tunnels is almost at street level. The building had to be founded at restricted areas between and beside the tunnels, partly on top of old brick foundations. The tunnel structures were to be left completely unloaded by the new building.

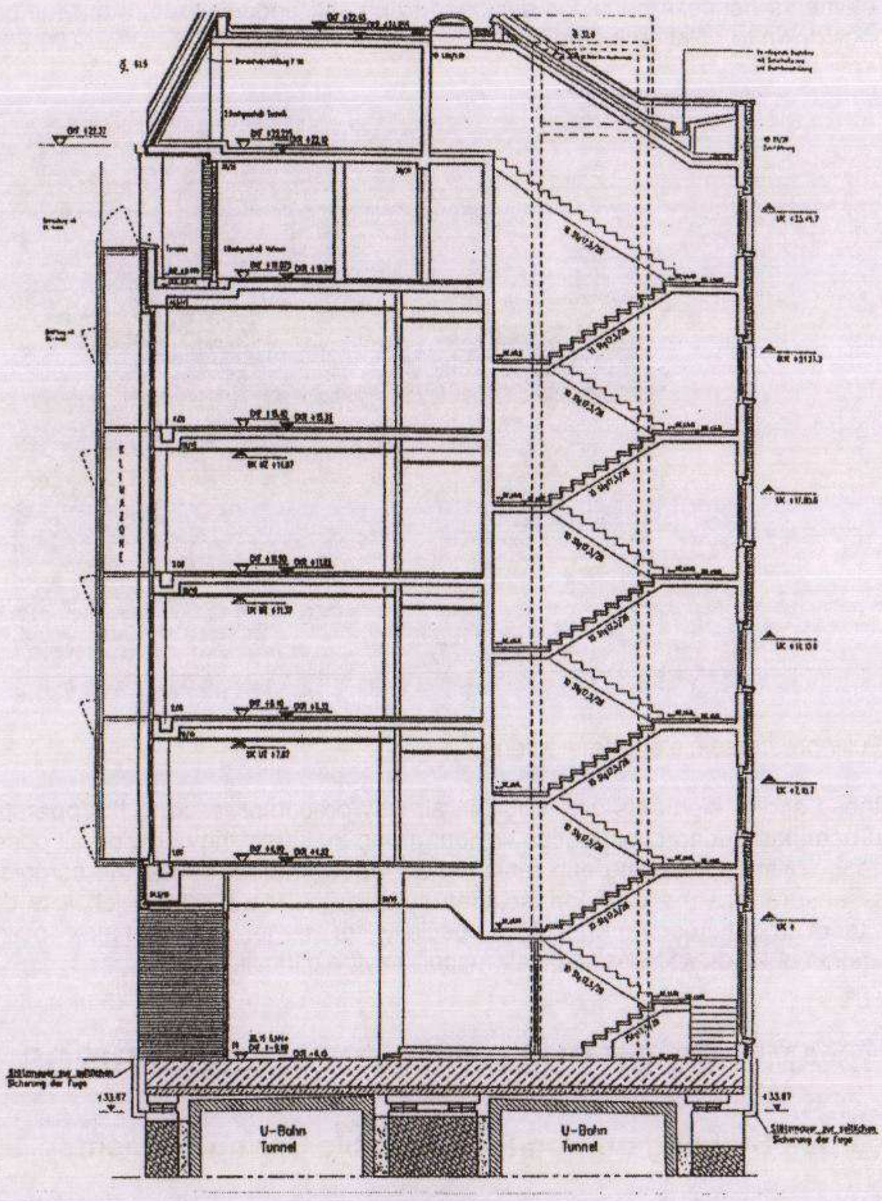

Fig. 5 Cross section of spring supported building above 2 tunnels

After re-activating the old brick foundations between and beside the tunnels and preparing a well-levelled concrete finish, the spring elements were put in place. A steel cover plate was arranged then on top of the elements serving as lost shuttering for a stiffening superimposed reinforced concrete layer. On top of this layer prefabricated concrete slabs were arranged to bridge the tunnels and to support a further 760 mm in-situ slab designed to support the building. Later on, the joints with the adjacent buildings were formed by means of mineral wool.

As the springs started being active immediately after the first loading was brought up, measurements were carried out at several stages of the ensuing construction works. The results proved clearly that the isolation efficiency increased with the loading respectively with the increasing spring deflections.

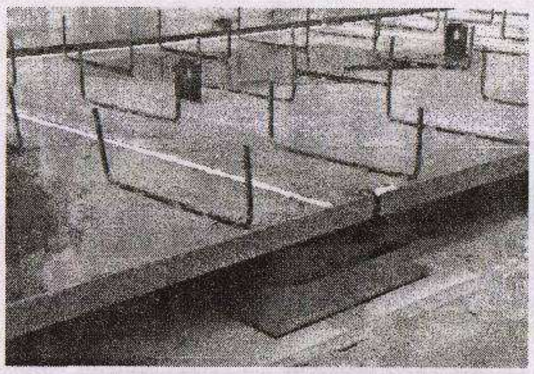

Fig. 6 Steel shuttering on spring element

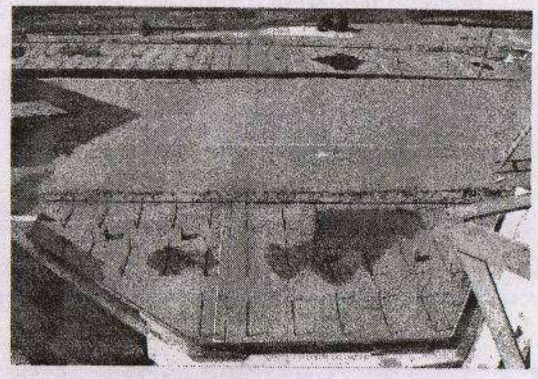

Fig. 7 Steel shuttering beside tunnel

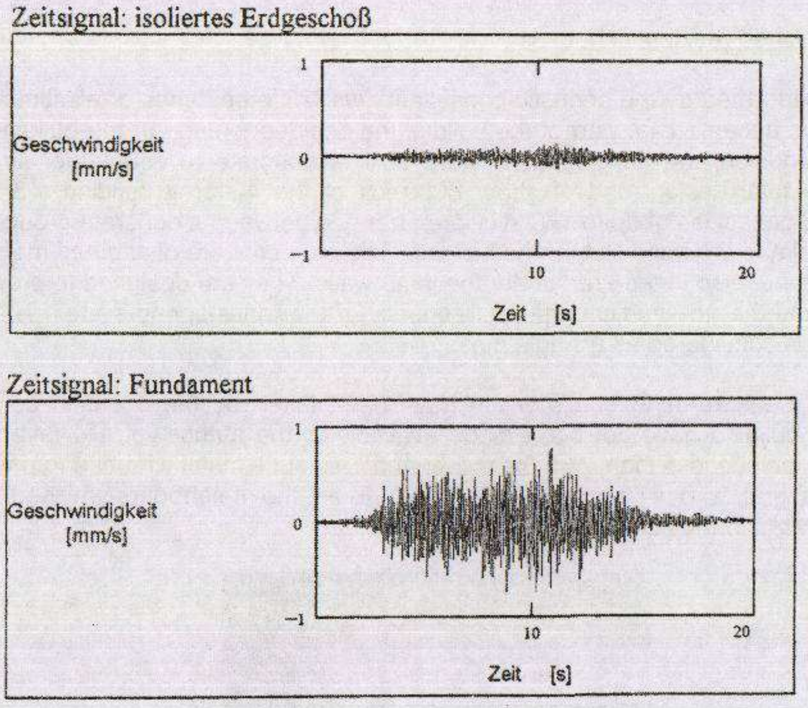

Fig. 8 Velocity signals above and below the isolation system

5.2 Victorian Style Residential Houses on Partly-Prestressible Spring Elements

Two new Victorian style residential houses were built in north-west London on one of the oldest railway tunnels built in 1838. Neighbours living opposite on the other side of the street on the same tunnel had to get used to vibrations clearly perceptible in their dwelling every time a train passed by. The new owners of the building did not want to undergo the same situation and to have to accept an inevitable devaluation of the property.

Fig. 9 Spring supported residential houses

After tests were performed by the acoustic consultant[1)] with different types of elastic bearings on a test structure which became later part of the building he decided to support the buildings on GERB steel springs. In addition, the building walls were built of concrete to counteract structure-borne noise. Due to the total design load of about 6000 kN of the 4-storey building, 43 small spring elements with load capacities of up to 180 kN were arranged between a concrete ground mat placed on top of the tunnel and the base slab of the building. The elements are distributed mainly below the outer building walls but also in the area under the inner walls. They are designed to provide a 3.5 Hz system. That means that the vertical natural frequency of the mass-spring-system is 3.5 Hz when the whole building is considered as a single mass.

Unfortunately the measurement results which have been taken by the acoustic consultant after completion of the building have not been made available to the author yet. However, there is no better evidence of the success than from the owner and resident himself who had to pay for the anti-vibration measure and who is completely satisfied. Even the neighbours 'missed' the familiar vibrations when invited to the house warming party.

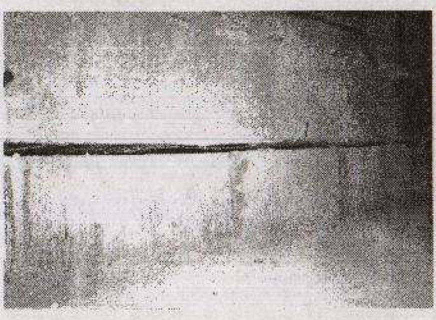

Fig. 10 Dynamic joint with spring elements protected behind precast blocks

5.3 IMAX Cinema on Fully-Prestressible Spring Elements

The British Film Institute decided to build the largest IMAX cinema in the UK just at one of London's most busy and noisy location in the very centre of the Waterloo roundabout. Beside several other challenges like the noise from road traffic, elevated train tracks, and aeroplanes flying at low levels destined for Heathrow there were two rumbling underground tracks to be considered being not far below ground level directly under the cinema building.

Fig. 11 IMAX Cinema London/Waterloo

Measurements performed by the acoustic consultant[2)] revealed the need for a low frequency bearing system to protect the building from noise and vibrations. A 3.5 Hz GERB system was chosen and arranged on top of 3 circles of columns. The spring elements carry a circular reinforced concrete slab forming the base for the steel superstructure.

Fig. 12 Spring elements on steel column heads

Fig. 13 Cladding covering spring elements

Further measurements were made at several construction stages. The results are depicted in Fig.14. They show an insertion loss of 18 dB in the auditorium. Around a 25 dB reduction was achieved when comparing final vibration levels in the first floor with those in the ground on the site prior to any works commencing.

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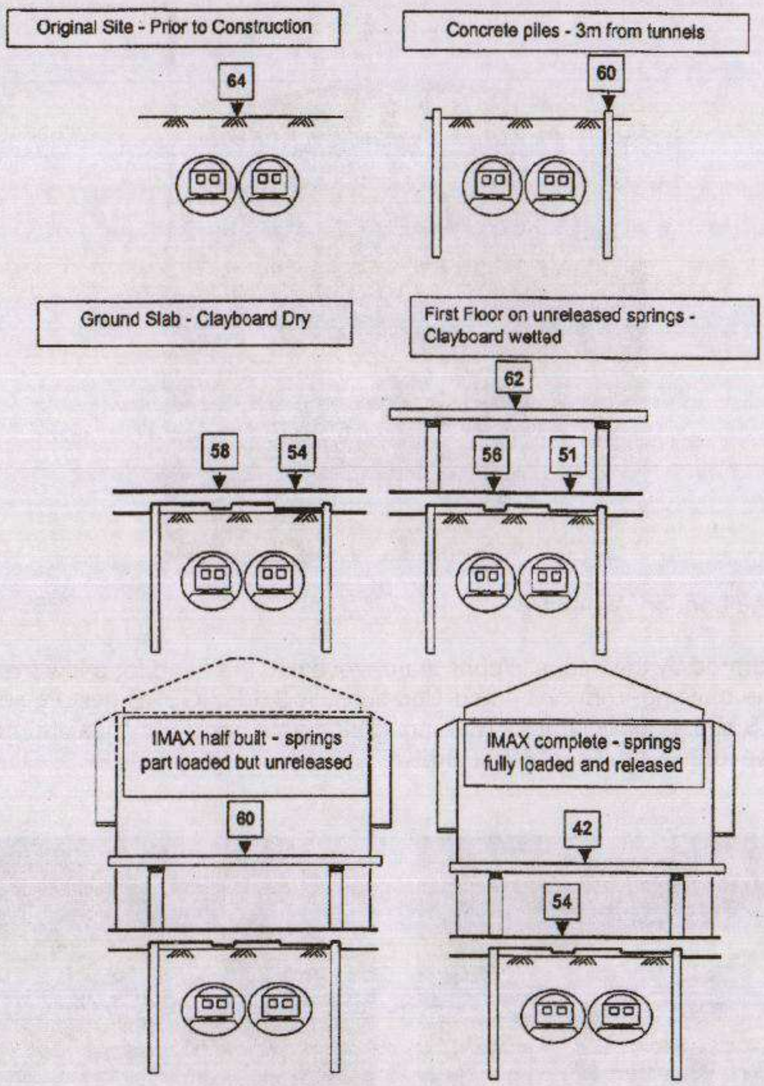

Figure 4a - Vibration from Underground Trains

Max. Acceleration Levels, dB re 10^{-5} ms^{-2} at 31.5 Hz Octave Band

Fig.14 Measurement results

[1] Civil Engineering Dynamics Ltd.
[2] Bickerdike Allen Partners