II

External Damping as a Means of Controlling Vibration in Modern Roofs

L'amortissement extérieur comme moyen de contrôle des vibrations dans les toitures modernes

Äussere Dämpfung zum Zweck der Vibrationskontrolle in modernen Dächern

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Professor Wakabayshi has described the favourable effect of damping by energy absorption in connection with seismic structures.

1. Introduction

Roof structures, and in particular cantilever structures, such as Grandstand roofs, are especially susceptible to wind excited vibration. Wind provides exciting forces and a roof has to be restrained in order to increase its fatigue life. The magnitude of vibration can be controlled either by increasing the stiffness of the roof or by adding damping to the system. The addition of damping is generally preferable since the resulting structure can be lighter and consequently more economical. In addition the energy produced by the wind forces is dissipated within the damping system rather than the roof itself and consequently the parts designed to absorb and dissipate energy energy, namely the dampers, do the work rather than this being undertaken by the structure of the roof.

The purpose of this paper is to illustrate how modern thin roofs are designed and also how damping can be incorporated into these designs so as to ensure satisfactory life whilst imposing minimal limitations on the overall configuration. The object of the paper is to describe three methods of applying damping to roof structures of different forms and show how the damping elements can be incorporated without imposing limits on either the structural or the architectural aspects of the basic solution. This problem has assumed greater importance with the introduction of prestressed concrete since the monolithic and light structures that result possess little internal damping.

The authors describe damping arrangements in two completed structures and one detailed project.

The excitation of the roof can be caused by two factors, one being the gust frequency of wind which can generate a low frequency vibration and secondly the higher frequency vibration that can be excited due to the effect of the aerodynamics on the roof; usually brought about by the build-up of vortices and the rate of shedding of these vortices from the leading and trailing edges of the roof. This characteristic is well known in aerospace technology and is the prime cause of flutter of aircraft wings.

2. Cantilever Roof for Doncaster Racecourse Grandstand, England

The roof, cantilevering 17 m, and carrying a structure weighing 27 tons accommodating Judges and Television facilities at the end of the cantilever, was completed in 1969. Lightweight concrete was used as the cranes available had limited carrying capacity[1].

Figures 1 and 2 show sections of the roof element and grandstand structure. Figure 3 shows a photograph of the front of the grandstand, with the Judges complex at the tip of the cantilever. Figure 4 shows a view of the vibration isolation and damping system.

It had been discovered on another racecourse with a similarly positioned Judges complex that due to wind excited vibration a great deal of discomfort was felt by those occupying the complex and severe limitations were imposed upon cameramen operating television and press cameras due to the oscillation of the structure.

The design was first conceived to provide a vibration isolation system for the Judges Box so as to eliminate the transmission of vibration from the roof to this complex, and additionally to ensure even load distribution across the nine supporting elements.

The natural frequency of the roof was determined to be of the order of $2\frac{1}{2}$ Hz and consequently it was decided to support the entire Judges/Press complex on large helical spring vibration isolators with a vertical resonant frequency of 0.8 Hz. The structure is located by a parallelogram linkage so as to permit movement in a vertical plane only and eliminate any rocking that would result had this additional restraint not been provided. With this system any vibration within the roof is effectively eliminated from the boxes and consequently no discomfort or limitation of use is experienced in the complex.

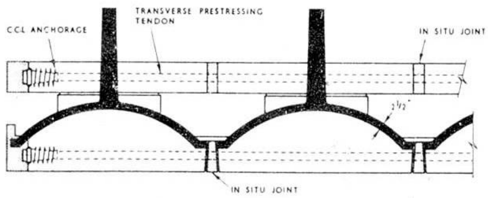
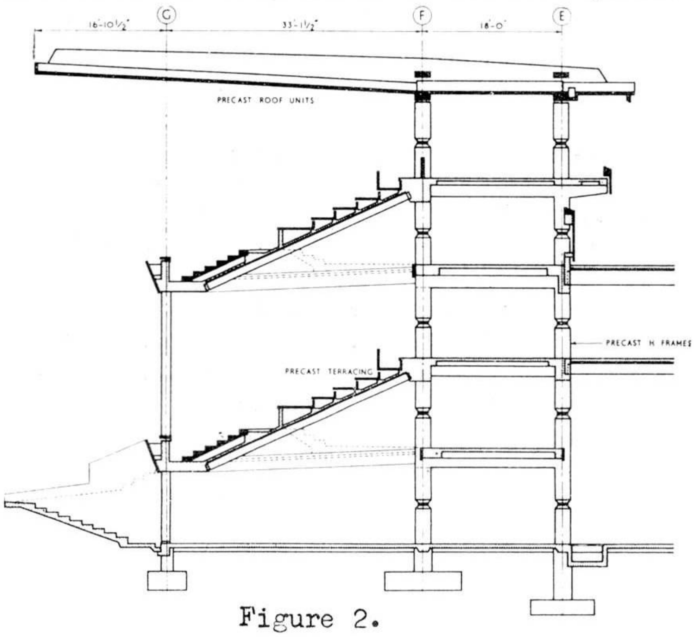


Figure 1.



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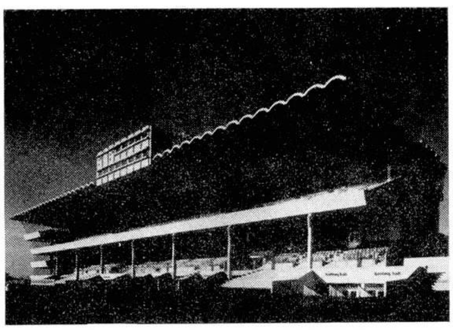

Figure 3.

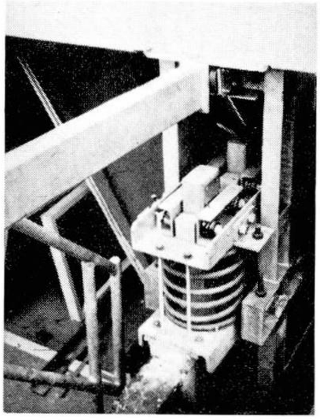

Figure 4.

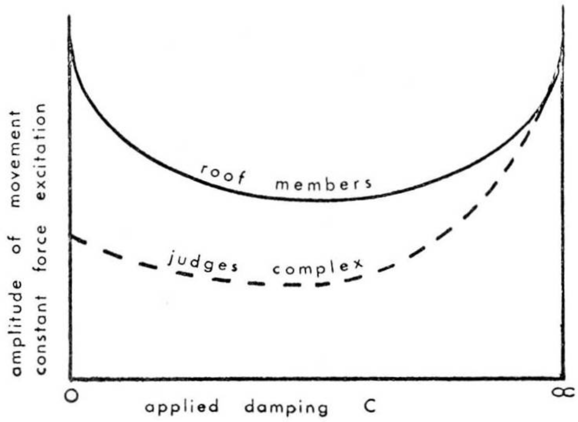

Figure 5.

Friction damping elements are interposed between the roof structure and the box complex. In the first instance these dampers restrict the build-up of amplitude of vibration caused by any excitation within the boxes at or near the resonant frequency of the spring system which could be caused by movement of personnel within the boxes or wind gust conditions. These frictional dampers are adjustable and are adjusted to give optimum results.

The complete system also serves as an auxilliary mass damper and will therefore reduce the amplitude of movement of the roof itself. This reduction of movement of the roof which is illustrated in Figure 5, will also reduce the amplitude of movement of the box complex since the input vibration level is lower.

From the point of view of the roof members alone the effective damping force should be a maximum to reduce movement, however as the damping increases so the transmission of vibration from the roof to the box also increases. The damping was adjusted by experimental methods to achieve optimum conditions whereby the transmission to be box when the roof is excited by wind forces is reduced to a minimum and also the dissipation of energy from the roof is at a maximum.

Since the cantilever beams supporting the Judges Box carry the mass at the end seismically supported, the resonant frequency of these beams is higher than would be the case had the boxes been rigidly fixed at the tip, therefore the overall dynamic stiffness of this part of the roof is greater and consequently the life of these members will be extended.

3. Grandstand at Sandown Park, England

In this case the roof design relies on stainless steel suspension cables. Figure 6 shows a cross section of the grandstand structure. The construction consists of prestressed concrete members positioned 6 metres apart and linked with lightweight transparent plastic roofing (Figure 7.).

It was decided that the only practical place for the positioning of any damping devices was at the highest point of the supporting cables, and consequently the bearing blocks that carry the cables through the centre pillars are located on a friction material designed so that as the roof vibrates, the cables will stretch and the bearing block will move horizontally by half the amount of the extension (Fig.8). The degree of damping in this instance is not as great as at Doncaster, but it is adequate to reduce the movement of the roof to an acceptable level. Enough safety is available for high strength stainless steel of lower fatigue limit than that of carbon steel for satisfactory performance.

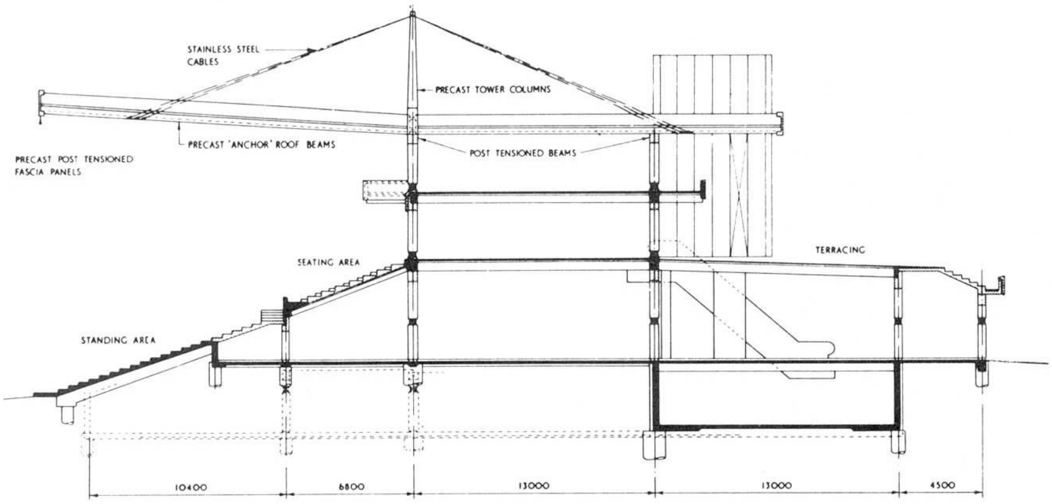

Figure 6.

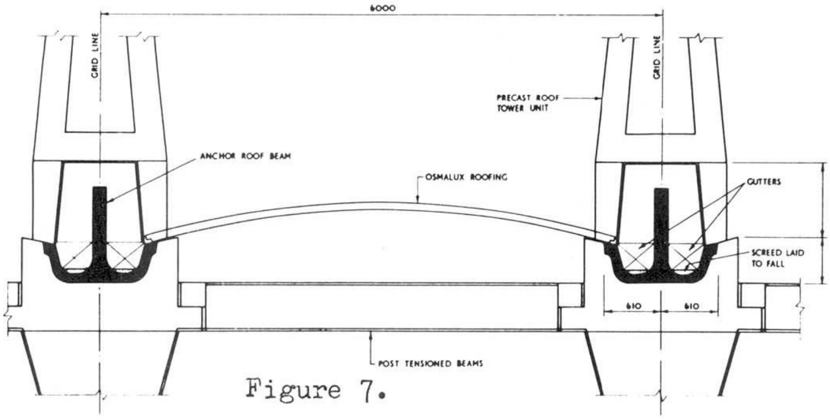

Figure 7.

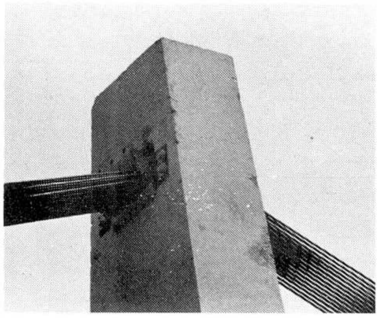

Figure 8.

This application of damping is particularly interesting as it shows how it was incorporated within the design whilst imposing negligible extra cost and no change to the overall configuration of the structure. The additional cost of providing damping was only a few hundred pounds compared to the total contract price of approximately £2m. Despite the light weight the roof has been found to be very stable during recent high velocity and gusting wind conditions.

4. Calgary Exhibtion and Stampede Grandstand, Canada (Project)

Figure 10 shows a cross section of the grandstand structure. Figure 9 shows a photograph of a model of the complete project.

In this case a design study has been carried out and model tests undertaken to determine the effect of damping in varying configurations. The basic design of a grandstand precludes any attachments to the forward portion of the roof and consequently in this instance the only practical place to apply damping was along the line of the roof directly above the rear row of seats in the grandstand. These dampers would be positioned to act both in the vertical plane and also angled at 45° to the vertical such that damping would be achieved vertically and on any horizontal movement of the roof perpendicular to the line of the seating (indicated on Figure 10).

A fibreglass model of the roof was constructed and subjected to constant force vibration on a moving coil vibrator and various damping arrangements were tested. From the model tests carried out it is possible to determine the size and form of damping system to be installed in the full scale project (Figure 11).

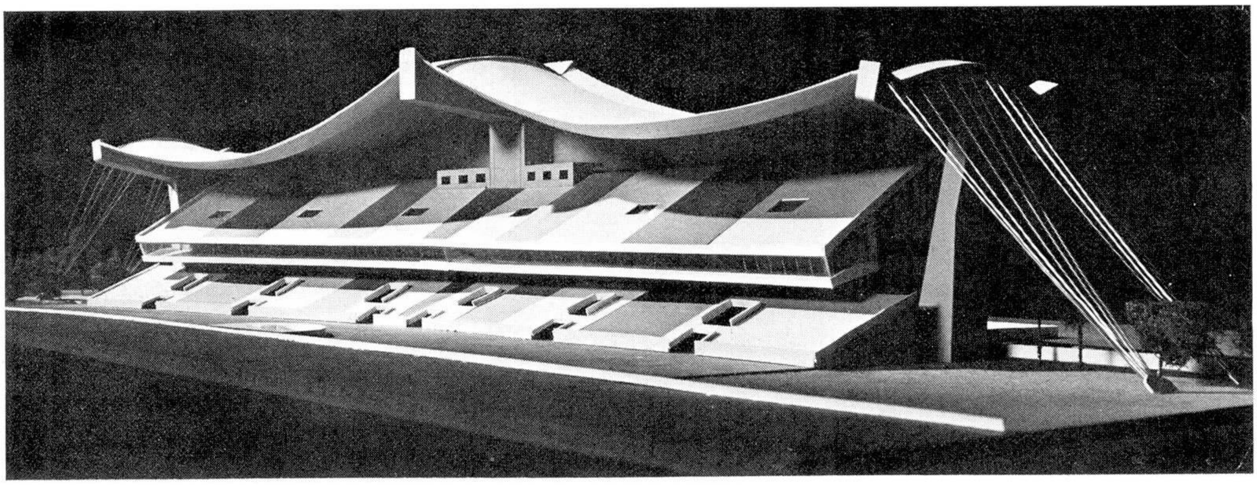

Figure 9.

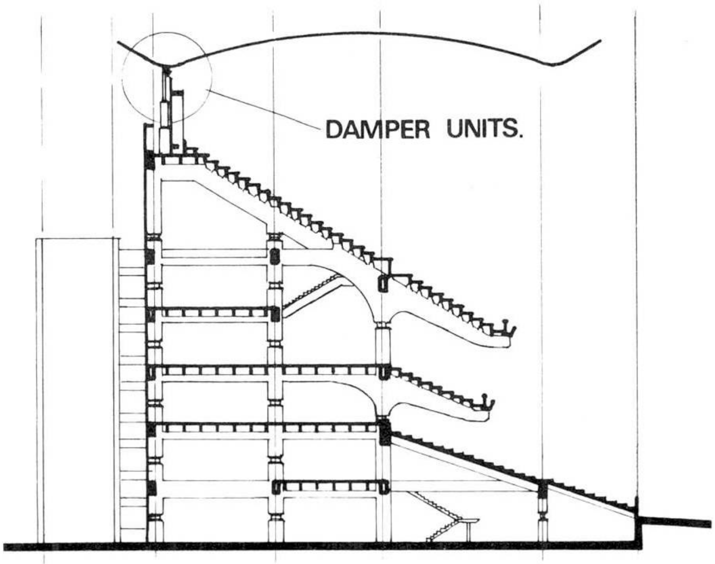

Figure 10.

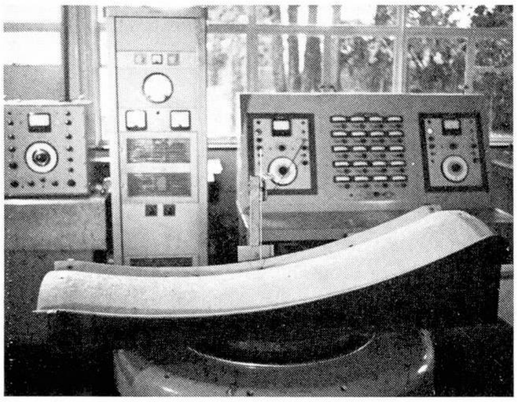

Figure 11.

The cost of testing together with that of the damping system was assessed to be under $100,000 whereas increasing the weight and stiffness of the roof to be safe without dampers could have easily reached or even exceeded $1m.

This particular structural solution was not finally proceeded with, as due to strict budget limitations a saving had to be made. This was achieved by moving the whole grandstand back from the arena, decreasing the number of seats at the top balcony and adding them at ground level. The width of the roof, covering seats, was reduced from 33.5 m to 20 m enabling adoption of cantilever solution within the budget limitations.

5. The advantages of lightweight damped roofs

In the paper by Abeles[2] under Theme V, it has been pointed out that certain stiffness is required for structures subjected to wind vibration to ensure that the amplitude is not too high and the natural frequency differs from that of vortex shedding frequency at characteristic wind velocity. With the addition of suitable dampers these limitations can be overcome and light modern roofs can be constructed safely and economically. This was achieved in all three examples by the combination of structural design and added damping at low cost.

The weights of the three roofs are 244 kg/m^2, 165 kg/m^2 and 220 kg/m^2 respectively. These compare very favourably with a weight of 650 kg/m^2 at which according to K. Yokota[3] of the Aoki Research Centre, Tokyo, rigidity of a structure was obtained for the roof of the famous Myoden temple of the Sho Hondu complex, Japan.

References

1. T. Maciag "The Prestressed Lightweight Concrete Roof for Doncaster Race-Course Grandstand", paper presented at the Sixth International Congress of the Fédération Internationale de la Précontrainte, Prague, June 1970.

2. P.W. Abeles "The Resistance of Prestressed Concrete to Dynamic Loading, Its Fatigue Resistance; Miner's Hypothesis", Theme V.

3. K. Yokota "Rigid Members Frame 22,000 ton Hung Roof", Engineering News Record, August 17 1972.

SUMMARY

It has been shown that the combination of lightweight design with added damping can result in the construction of roofs giving satisfactory performance at a total cost a fraction of that of the rigid high density design. It has also been demonstrated how the damping devices can be incorporated into the design without imposing limits on the structural or architectural aspects.

RESUME

On montre dans ce travail que la combinaison de structures de couverture légères et de systèmes d'amortissement permet de construire des toits au comportement satisfaisant et d'un coût total inférieur à celui des structures courantes rigides plus lourdes. On explique aussi comment le mécanisme amortisseur peut être intégré à la structure sans imposer des limites à l'aspect structural ou à l'aspect architectural.

ZUSAMMENFASSUNG

Es wurde gezeigt, dass die Kombination der Leichtbauweise mit eingebauter Dämpfung in modernen Dachkonstruktionen mit befriedigendem Verhalten die Gesamtkosten auf einen Bruchteil senken kann, verglichen mit der Ausführung mit den üblichen Baustoffen. Ebenso wurde gezeigt, wie die Dämpfungsvorrichtungen in den Entwurf mit einbezogen werden können, ohne den baulichen und architektonischen Aspekten Grenzen zu setzen.