Seismic Energy Disssipation of a Building using Friction Damper

Shilpa G. Nikam, S.K. Wagholikar, G.R. Patil

Abstract -- Conventional methods of seismic rehabilitation with concrete shear walls or steel bracing are not considered suitable for some buildings as upgrades with these methods would have required expensive and time consuming foundation work. Supplemental damping in conjunction with appropriate stiffness offered an innovative and attractive solution for the seismic rehabilitation of such structures extensive use of friction joints in new and retrofitted buildings has demonstrated the economic advantages of this form of device to control the amplitude of building motion due to seismic action. The paper highlights in particular the use of friction devices in conjunction with rigid structural frames, either steel or concrete. The introduction of supplemental damping provided by friction devices dramatically reduces forces on structure, amplitude of vibration and floor acceleration.

KEYWORDS: Friction damper, slip load, Hysteresis, Energy Dissipation

I. INTRODUCTION

In 1979, the friction damper was invented, to be used in buildings for improving seismic performance, inspired from the friction brakes used in automobiles The friction dampers are, by far, the most widely adopted means to dissipate the damaging kinetic energy from the structures. The friction dampers dissipate a large amount of energy, which is evident from its highly nonlinear hysteresis loop, through dry sliding friction. The friction dampers work on stick-slip phenomenon, in which slip load is the most important parameter. Slip load is the load at which the friction dampers are activated and slippage occurs, thereby developing frictional force. Two most prominent types of the friction dampers which have successfully been used around the world are the Pall and the Sumitomo friction dampers. The friction dampers are generally installed in the cross-bracings of the building frames, called here as friction damper frame (FDF). In the braced frame (BF) of the buildings, owing to increase in stiffness, displacements are reduced; however, base shear of the structure

increases as compared to that in the conventional moment resisting frame (MRF) of the buildings under earthquakes. However, providing the friction dampers in the braces would help reduce the base shear induced in the columns because of energy dissipation. Also, the number of storeys of the structure affects the reduction achieved in the seismic response.

Sliding friction connections, to dissipate seismic energy, were initially studied and tested as joints between the vertical edges of coupled concrete shear walls. As the joints slip, the cantilevered walls provide the elastic restraint required to create the centering action that ensures a negligible residual displacement after the earthquake. The capacity to dissipate the input of seismic energy with a relatively small travel in the joints, thereby controlling the amplitude of the oscillations, was convincingly demonstrated. Instead of relying on cracking concrete and yielding steel as a means of energy dissipation, reusable sliding joints can limit damage to secondary items and greatly simplify post-earthquake rehabilitation.

II. STRUCTURAL PERFORMANCE OF DAMPER

Under the action of horizontal wind forces the building acts as a braced frame, with the shear force resisted by the diagonals and the overall bending by the cantilever action of the structure, the members being subjected to predominantly axial forces. (Frame action is used for gravity loads). Forces to cause joints to slip will be chosen such that slipping is improbable, and the entire system remains elastic, for the expected wind conditions, and minor earthquakes. When the ground acceleration reaches the initiating design value, slipping occurs, energy is dissipated, the building motion ceases to be elastic and the natural frequency changes, thereby eliminating the possibility of resonance. As the intensity of the ground motion increases, more joints slip and the travel in the joints increases, until the limiting design earthquake is reached, at which point the distortion of the frame is just short of that which would cause it to yield. It is to be observed that in a rigid frame relying on yielding to dissipate energy, the building must have deflected to the point where yielding occurs before damping takes effect; with friction dampers all the required energy dissipation has taken place before the frame yields. This represents the condition for the projected maximum earthquake. For more intense ground motion the rigid frame will yield, adding to the rate of energy dissipation. Collapse is difficult to predict, because the structure continues to be an effectively braced frame. The limit may be due to fracture at a yield hinge, buckling of a column, or instability due to the P-δ effect. To reach this extreme case requires that sufficient travel is allowed in the slip joints to permit the development of the fully plastic structural system, otherwise failure in a diagonal will occur due to the impact when the available slip travel is exceeded. These stages correspond roughly to the levels describe in FEMA [1997], which are: Operational, Immediate Occupancy, Life Safety, and Collapse Prevention.

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There will be a specified intensity of earthquake for each level of damage, which is selected according to the value put on economic costs and public safely. During seismic activity the damping decrement increases with amplitude and is such that the accelerations in the building do not exceed that of the ground. After experiencing the design earthquake, because of the centering action of the elastic frame and the random nature of the ground motion, the building returns to its original position within a small tolerance, and requires no adjustment to be ready for the next earthquake. The combination of friction dampers and the elastic building frame creates a resilient, displacement-dependent, energy dissipating system. When included in the original design of a braced rigid frame, the system minimizes the overturning forces on the foundations and, hence, minimizes concerns with soil-structure interaction. When friction damped braces are added to existing rigid frames, lateral strength and rigidity are enhanced, moments in the columns are reduced, and axial column forces are increased.

III. CHARACTERISTICS OF FRICTION DAMPERS

When there is no seismic activity there is no action in the damper, which can support its design static load indefinitely, so there are no problems of wear or fatigue. Dampers act as fuses, limiting the force that can be imposed on the members that they protect. Because the hysteresis loop is rectangular it provides the maximum possible energy dissipation for a given force and travel, which is independent of velocity and frequency. Performance is consistent and reproducible, providing protection against a series of earthquakes without the need for servicing. Each damper is manufactured to slip at a specified force, within a specified tolerance over the specified travel. The slip force is controlled by the tension in bolts holding together the sliding elements. Specially formulated surface treatments give the type of performance needed. The initiation of slipping should not require a significantly higher force than that needed to continue sliding, and the motion should reverse without "sticking", with no chatter during sliding. The coefficient of friction is about 0.2, but the value is not of great importance, because the slip force depends on the bolt tension, which is adjusted to create the force specified. Contact surfaces should be rigid; and bolt stresses should be kept below the yield stress, as any creep would reduce the bolt tension and, hence, the slip force. Energy dissipated during sliding increases the temperature of the damper. While having no influence on the characteristics of the sliding surfaces, the thermal expansion can cause an increase in the bolt tension, thereby increasing the slip force, which can be of benefit during continuous seismic activity. However, using a number of cycles well in excess of that which will occur in an earthquake, tests have shown that the resulting change in slip force is within the design tolerance. In the event of an earthquake, the extent of the travel of any joint that has slipped will be clearly recorded. As this travel is directly related to the deflection of the structure, and hence to the moments in the rigid frame, it will act as a "damage indicator", showing whether or not the main structural frame remained elastic.

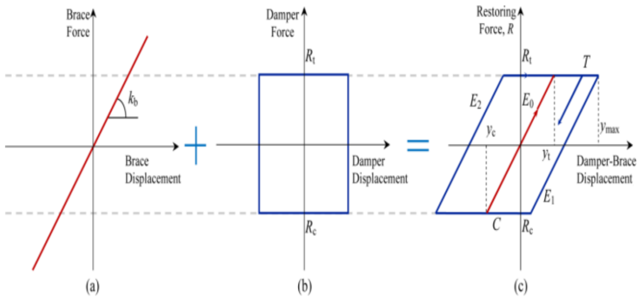

Figure 1. (a) Elastic behaviour of brace, (b) hysteretic loop of friction damper, (c) resultant elasto-plastic behaviour offriction damper in brace

IV.LOADS OF FRICTION DAMPER

Analysis will have determined the optimum total slip force required at each storey level. The actual behaviour of the building changes very little with ±15% variations in this optimum value. Analysis will also show if there is any advantage in changing the value from storey to storey. The number of sliding braces to be introduced at each storey, to provide the total required slip force, depends on a number of factors, including the availability of locations, the preferred style of bracing , the economic balance between the number of dampers and the unit cost, and the possibility of multiple dampers in parallel in a single diagonal. Dampers increase in size and weight with increasing slip load. As the friction dampers are factory assembled for site installation, the size of the assembly is of practical interest, with the concomitant costs of the bracing members themselves and their attachments. The highest slip load to date is over 2MN, and the longest travel is almost 400 mm, thus there is a wide range from which the optimum can be selected

V. TYPES OF STRUCTURAL SYSTEMS

Friction dampers provide a rectangular hysteresis loop, giving the maximum energy dissipation per cycle, but they possess no centering capacity. Consequently they must be incorporated into elastic systems which contribute the necessary restraint as the joints slip. This limits their use to building types which can permit overall elastic shear distortions without structural damage, such as coupled shear walls and braced steel or concrete frames which will be designed on the basis of strong-column-weak-beam when acting as a rigid frame under lateral loads. Masonry enclosures and concrete shear walls are rigid in shear, and do not permit the distortion needed, making them unsuitable for the use of friction dampers. Low rise framed buildings with metal cladding or panel walls will be expected to suffer some damage to the enclosure unless the attachment system is designed to permit the required movement. For high rise buildings the wind forces may exceed the earthquake forces, and hence control the design, making friction dampers unsuitable; if they are to slip for seismic forces they would slip under wind action. There is thus a fairly well defined range of building heights and types for which friction dampers provide the solution for controlling the response to seismic activity.

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Complete assemblies of damper are shipped to the site, ready for installation with no further adjustments. Each damper is provided with the means to attach it to the structure, either by welding or bolting, which can accommodate any minor dimensional changes required. When incorporated in original structures, the connections can be chosen to suit the contractor's methods. When added to existing braced frames, the braces can be cut and the dampers installed, with a minimum disruption of the structure. Should the dampers be introduced into compression diagonals, the assembly is required to possess bending rigidity comparable to that of the member. When damped braces are added to existing rigid frames, connection details need careful attention, as does the revised distribution of forces in the structural system. In service the sliding surfaces are essentially immune to corrosive attack but the assemblies are painted to provide an additional seal in order to maintain the performance of the original installation


Figure 2.Friction damper in single diagonal bracing
Figure 3. Friction damper in chevron bracing (inverted)

VI. METHOD OF ANALYSIS OF FRICTION DAMPER

Attempts to provide simple methods of analysis have not been very successful. The varying behaviour of the structure as the amplitude of sliding progresses makes it unreliable to use an equivalent rigidity, or equivalent damping which ranges from almost zero in the elastic range to well in excess of the critical value at the extreme deflections, and equivalent static horizontal forces will vary in both magnitude and location with the performance level required. A full nonlinear time history analysis, using ground motion records appropriate to the location, has proved to be the only acceptable means of establishing the adequacy of the arrangement. Analysis of two-dimensional motion is sufficient for the majority of structures, but, if there is an offset between the centre of rigidity and the centre of gravity, a three-dimensional analysis is preferred.

Most national codes permit the use of non-traditional energy dissipating devices, but require that a complete analysis be conducted, a task for which not all engineering offices are prepared. The codes that address the problem, such as FEMA [1997] make use of some simplifying assumptions to permit direct design, but indirectly illustrate that a full analysis is usually needed. Even FEMA does not include energy dissipating devices in 'Simplified Rehabilitation'. Because the building motion is sensitive to the composition of the ground motion, analysis using different records is often required to ensure that there are no surprises in the behaviour. Prototype testing is required to demonstrate the performance of the damper when subjected to the number ofcycles and travel expected during the maximum credible earthquake (Basic Safety Earthquake-2 in FEMA,1997). 20 cycles to maximum travel at the design slip load, is specified. A variation of ±15% from the target value is permitted. The number of cycles is sufficient to confirm the uniformity of the performance and the influence of the temperature rise. Force-displacement loops are plotted to show any changes in the energy dissipated from cycle to cycle. There is no motion in the dampers during normal service, so no question of fatigue arises, thus tests with multiple cycle low value loads are not appropriate. In production, the slip force is kept within ±10% of the design value to ensure that the specified tolerance is satisfied, and acceptance tests on the finished assembly are confined to demonstrations of the force-displacement properties. As the production process itself involves multiple cycles of slipping, the faying surfaces are free from asperity, giving the smooth slipping demanded Random checks are made on about 10% of the dampers before shipping.

VII. INSTALLATION COSTS

The principal attraction of friction dampers is the facility with which they can be installed in structures. They are incorporated in new or existing buildings of the appropriate type with little modification to the system. This leads to savings in construction costs that usually far outweigh the cost of the dampers themselves. For a new building, braced rigid frames make the least demand on the foundations. When retrofitting a braced frame, by introducing friction dampers in the existing braces, there is no change in the structural framing and very little change in the structural action. Adding braces to an existing frame usually strengthens the structure with no need to modify the foundations. Retrofitting a building may be possible without disrupting the occupants, thereby providing an additional saving. Where there is a code requirement to be satisfied, the savings in the costs affected by adopting friction dampers merits their use, but there may be an even greater saving after an earthquake as the costs of rehabilitation of the building will be much lower owing to the reduced damage, both structural and secondary. Should the rigid frame actually suffer yielding, the structural system remains intact, and the conditions for "immediate occupancy" might well be satisfied.

VIII. CONCLUSIONS

The problems encountered in creating reliable friction dampers, which possess a predictable performance, and the methods of introducing them into new and existing structures, have been resolved, and the end result is the most economical system to provide a degree of protection against seismic activity for framed medium-rise buildings. Improvements in the dampers and their utilization are under continuous study and other friction devices for other types of building are being developed.

The use of frictional damper has shown practical economical and effective approach to design earthquake resistant buildings also they can be incorporated to existing frame for retrofitting. Some technical and economic advantages of friction dampers are

1. Offer initial cost saving in new construction or retrofit of existing building.
2. Simple in construction and inexpensive in cost.
3. Possess large rectangular hysteretic loop with negligible fade over many cycles of reversals.
4. Very high energy dissipation capacity hence less quantity of dampers required.
5. Reliable and maintenance free performance, No repair or replacement needed after earthquake.

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