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THE MAKING OF MEGA PALL FRICTION DAMPERS FOR TORRE CUARZO OFFICE TOWER IN MEXICO CITY

Avtar Pall[(1)]

[(1)]President, Pall Dynamics Ltd., apall@palldynamics.com

Abstract

The 600 feet (183 m) high steel frame tower is founded on piles. The preliminary time-history dynamic analysis by the project structural engineers, WSP Group in New York, have shown that higher modes influence to excite the structure above 11th floor, resulting in large story drifts. Introduction of supplemental damping by incorporating passive energy dissipation devices was considered to be the most economical solution. Pall Friction Dampers® (PFD) were chosen because they possess both stiffness and damping and are best suited to control story drifts. Beside their low cost, they are maintenance free and can be easily modified to suit site conditions.

The architectural constraints allowed limited number of braced bays. Therefore, dampers of very high slip loads up to 1950 Kip (8700 kN) were needed to control large displacements. This big capacity damper has not been manufactured so far. Generally, the demand for damper is up to 350 Kip (1500 kN) capacity. Therefore, the manufacturing / testing equipments are geared to damper size in demand. Upgrading the equipment is expensive and economically not justified. The making of Mega damper was therefore a challenge. Making an assembly of group of PFD units, in parallel, was thought to be a right solution for Mega dampers. The compact size of PFD units, made it possible to build an assembly up to 8 units. The desired design slip loads were achieved with assemblies of group of 2, 4 and 6 units. The architects have liked the appearance of PFD assembly and have boldly exposed Steel bracing with Mega Pall Friction Dampers to view - a showcase of The Art of Structural Engineering.

This paper describes the history of development of Pall Friction Dampers, from an idea to real application. The paper will also discuss challenges in the making of Mega Pall Friction Dampers and show the construction details. Hopefully, the development story will inspire young engineers to continue advancement of their innovative ideas for a better and safer world.

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Keywords: Passive energy dissipating devices; Seismic damper; Friction dampers; Dampers; Damping; Seismic retrofit.

1. Introduction

For better understanding and appreciation of the application of Mega Pall friction dampers in Office Tower, firstly, the history of the development of state-of-the-art technology will be discussed. Hopefully, the background history will inspire the young engineers to innovate to meet the present and future needs of society. The advice to young engineers is that if someone has an idea and he sincerely believe in it, he should follow it through to the end. Never give up.

"This research is dedicated to those engineers, who rather than blindly following the codes of practice, follow the laws of nature".

1.1 State-of-The-Art

The 1960 Great Chilean Earthquake of Magnitude 9.5, and 1964 Alaskan Earthquake of Magnitude 9.2, left more than 6000 people dead, 2 million homeless and property worth more than $3 billion was lost. "*Earthquakes don't kill people but the falling buildings do".* Therefore, safety of people is the concern of structural engineers. Saddened by the fresh images of the devastating tragedies, Avtar Pall a young structural engineer in India believed that buildings designed to building code requirements are not immune to destruction. The building code design philosophy is based on the considerations of economics and probability of occurrence of major earthquake. The primary emphasis is on life safety. The code provisions are: design structures to resist moderate earthquakes without significant damage; prevent collapse during a major earthquake. The reliance for survival is placed on ductility to dissipate energy during large inelastic deformations causing bending, twisting and cracking. The use of ductility results in permanent damage requiring very costly repairs, and in some cases, the structure cannot be salvaged. Pall believed that if a major portion of the seismic energy can be dissipated mechanically, independent of primary structure, the dependence on ductility of structure could be avoided.

Of all the methods available to extract kinetic energy from a moving body, the friction brake has proven to be the most effective, reliable and economical mean to dissipate kinetic energy and inhibit motion of machines, automobiles, railway trains, airplanes, etc. Nothing else has been able to replace it so far. In 1964, inspired by the principle of the friction brake, Pall strongly believed that similar to automobiles, the motion of vibrating building could be inhibited by dissipating seismic energy in friction. For next few years he kept thinking about the location and configuration of the friction brake for the buildings. For a friction brake to work, it needs external force and displacement. The use of sensors and electricity/generator for power are expensive and unreliable. Ideally, the seismic brake should be located where there is relative displacement during earthquake and use the earthquake itself as prime-mover to operate brakes. The brakes should be located in secondary members like braces in framed structure and vertical joints in prefabricated panels and shearwalls. Their location in primary gravity load carrying members (columns/beams) should be avoided. At that time in India, computers and testing facilities were not available to undertake research of this kind. He was stuck. In 1975, he came to Canada to study for his Ph.D. He conducted hundreds of nonlinear time-history dynamic analysis and was convinced that putting brakes to buildings can significantly improve the seismic response of the structure, as he had originally thought.

1.2 Development of Pall Friction Dampers®

After thousands of hours R&D, Avtar Pall pioneered Pall Friction Dampers® (PFD)**.** In 1984, he founded his company Pall Dynamics Limited (PDL) in Montreal. He developed several types of PFDs for different types of building construction: Precast Large Panel buildings [1,6]; Friction-Damped Concrete Shearwalls [5]; Framed Buildings [2, Patent 1982]; Precast Concrete Cladding [7]; Friction Base Isolators [8, Patent 1982]. PFDs are simple and foolproof in construction. Pall had a passion to develop an ideal friction damper. Unlike friction brake for automobiles which can be changed when worn out, it is not easy to replace friction dampers in a building. Friction dampers for buildings must possess reliable and stable performance over long inactivity and over the life of building. Developing reliable friction is very difficult and tricky. Over more than a decade of R&D, he overcame the common problems in friction by choosing specially treated friction surfaces and unique manufacturing process. He studied the effect of coefficient of friction, normal stress on friction surfaces and effect of temperature rise on wear out of friction surfaces; stick-slip and cold welding phenomenon; effect of stress in bolt and number of wearing friction surfaces for each bolt on relaxation in slip load. He believes that temptation to economize by using higher coefficient of friction, more number of friction surfaces and higher stress in bolt should be avoided for the sake of long term performance.

Extensive research and testing has resulted in the perfection of achieving desirable friction. The performance of PFD is reliable repeatable, demonstrating large rectangular hysteresis loops with negligible fade over several cycles. PFD's are passive energy dissipation devices and require no energy source other than the earthquake to operate . They do not require any repair or replacement after the earthquake and are always ready to operate during aftershocks or new earthquake. They slip smoothly without any noise. With the emergence of PFDs, it has now become economically feasible to make performance-based design of buildings [16].

1.3 Proof Tests

PFD's have undergone rigorous proof-testing in Canada and the U.S. In 1985, the National Research Council of Canada proof-tested three 3-storey frames: Moment resistant (MR), designed according to code; MR frame with nominal bracing; MR frame equipped with PFD's, on a shaking table at the University of British Columbia, Vancouver [3]. The frame with PFDs remained damage-free even for earthquakes five times larger than the 1985-Mexico earthquake, while conventionally code designed frames got damaged at much smaller seismic loads. In 1987, the U.S. National Science Foundation tested a 9-storey frame structure, equipped with PFD's on a shake table at the University of California at Berkeley [4]. It was subjected to a series of very severe, simulated earthquakes; the frame structure remained damage-free even at the maximum capacity of the shake table (0.9g). Frame with PFDs was subjected to severe earthquakes for about a dozen times to show to new visiting group of engineers. The frame and PFDs were not damaged.

Fig.-2 Shake table tests at U.C. Berkeley [4]

1.4 Practical Applications

The first building with seismic dampers, was built with PFDs in 1987. It was Concordia University Library in Montreal [9]. Since then, PFDs are finding increasing application worldwide for new construction and retrofit of existing buildings. These have been used in more than 300 buildings around the globe. In 1998, the Boeing engineers were in search for the best technology for seismic retrofit of the Boeing Commercial Airplane Factory at Everett, WA – World's largest building by volume [14]. After a thorough search, they selected PFDs. Since then, Boeing is a repeat client and has retrofitted six more buildings with PFD's, saving more than $50 million. The City of San Francisco chose PFDs for Moscone Convention Center and saved tens of million dollars [19,20]. PFDs have been used in Wilshire Grand in Los Angeles as "Load-Limiting Device" and to control floor vibrations in Dancing Hall. Canadian Embassies in Beijing, China; Tehran, Iran; and Islamabad, Pakistan, are retrofitted with PFDs. In Montreal more than 30 buildings are with PFDs, Casino de Montreal [11], Canadian Space Agency HQ [10]; a dozen hospitals, and University buildings; Palace de Congress[18]. In Ottawa, about a dozen buildings including St. Vincent Hospital [17] and Justice Headquarters on Parliament Hill [13].

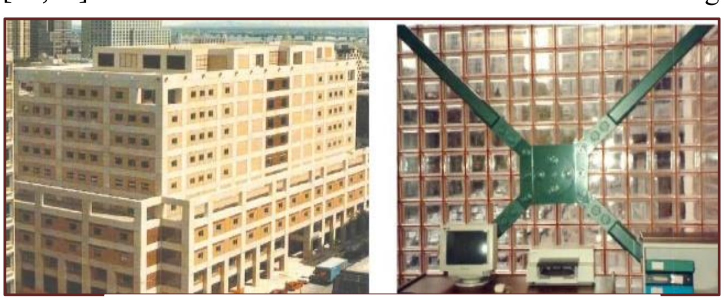
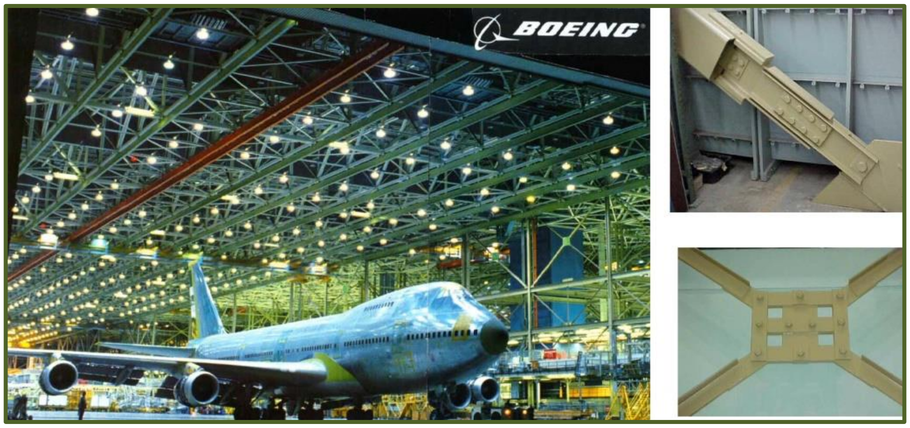


Fig.-3 Concordia University Library, Montreal [9]



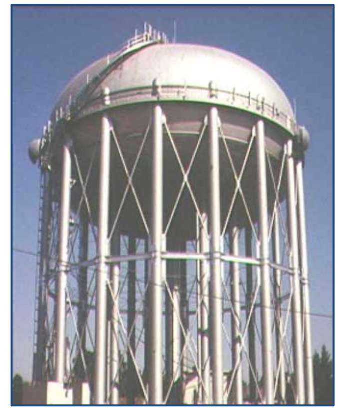


Fig.-4 Boeing Airplane Factory, Everret, WA [14]

Fig.-5 3M Gallon Water Tower, Sacramento,[12]

Fig.-6 Moscone Convention Center, San Fransisco

Fig.- 7 Casino de Montreal [11]

Fig.- 8 Saint Joseph Hospital, Patient Towers, Seattle, 40' Soft Story, Retrofitted with X-Brace PFDs.[15]

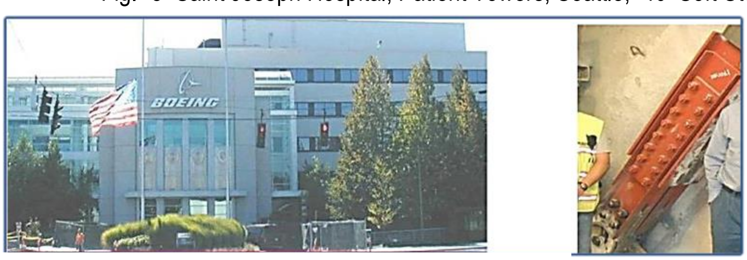


Fig.- 9 Boeing Development Center, near Seattle,WA

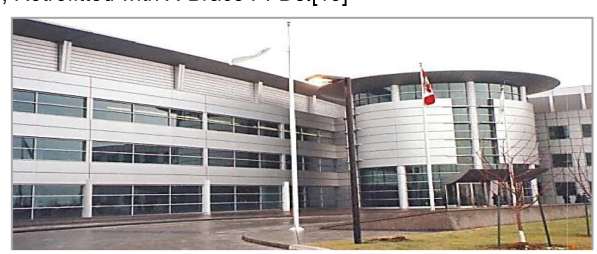


Fig.-10 Canadian Space Agency Headquarters [10]

Fig.-11 Justice Headquarters Building, Ottawa [13]

2. Torre Cuarzo Office Tower

Torre Cuarzo Office Tower is located on 26 Reforma Avenue, Mexico City, Mexico. The Steel frame tower is 600 ft. (183 m) high and is founded on piles. This building is for mixed-use; hotel, department stores, restaurants and offices. The design of this building is the work of Richard Meier Architects of New York in partnership with Diametros Architectos of Mexico City. The structural engineers are WSP Group in New York. Corey Steel of Mexico is the prime contractor The construction is likely to finish in early 2017.

2.1 Why Mega Pall Friction Dampers?

The preliminary results of nonlinear time-history dynamic analysis by structural engineers showed that higher modes influence to excite the structure above 11th floor, resulting in large story drifts. The use of heavier member sections was not economically feasible. Alternate solution was to introduce supplemental damping by incorporating passive energy dissipation devices in steel braces. Pall Friction Dampers® were chosen because they possess both stiffness and high damping, therefore, are best suited to control story drifts. Beside their low cost, they are maintenance free and can be easily modified to suit site conditions.

The architectural constraints restricted the use of only one braced bay on each of 4 exterior elevations and that brace served two floors (Fig.18,19). In the interior, there are 3 stages of two floors having 4 bracess on each face, forming a x-shape pattern (Fig.17). Due to limited number of braced bays, dampers of very high slip loads, up to 1950 kip (8700 kN), were needed to control large displacements. This big size of damper has never been manufactured. The largest damper in the world was 1500 kip (6,700 kN), used in a bridge in Japan. Generally, the demand for maximum damper capacity is about 350 kip (1500 kN). In general, the manufacturing and testing equipment are geared to damper size in demand. Upgrading equipment was expensive and not justified.

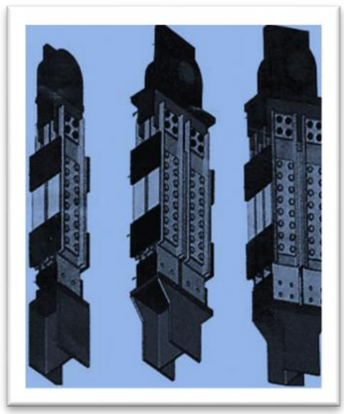


Fig.-12- Assembly of Group of 2,4,6 Units.

The challenge of making Mega friction damper was made posible by the compact size of PFD units. The design slip loads were achieved with assemblies of group of 2, 4 and 6 damper units. A group of 6 PFD units of 325 kip made an assembly of 1950 kip (8700 kN) damper. Table -1 shows composition of various assemblies.

The assembly is big and massive. The length of Assembly-1 is about 12 ft. (3.6 m) and mass 11 kip (5 tonne). It is difficult to handle this size damper in shop and transport. Making an assembly of group of PFD units does not require very skilled technicians and can be economically done by steel contractor. The PFD units were shipped to the contractor Corey Steel of Mexico, who made the assemblies of units. The finished assembly (Fig.3) gives a bold look and the architects exposed them to view as a showcase of the-state-of-art seismic control technology.

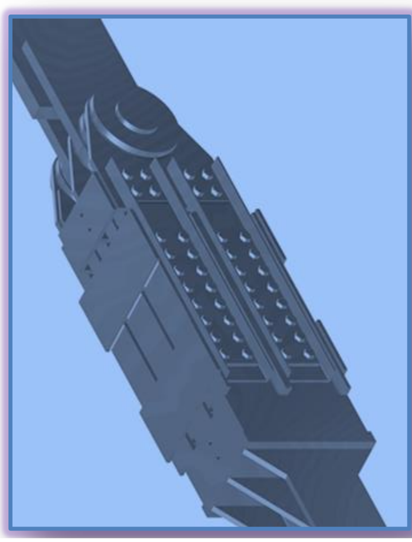


Fig.-13- Finished Assembly of 6 PFD units

Table-1- Composition of Mega Pall Friction Dampers used in Office Tower

MEGA PFD Assembly #	Slip Load / Stroke	Quantity	Composition of PFD Units	Total
1	550 Kip (2450 kN) / ±3.75” (95 mm)	28	2–PFD Type-1 275 Kip (1225 kN) / ±3.75” (95 mm)	56
2	1100 Kip (4900 kN) / ±7.25” (185 mm)	42	4- PFD Type-2 275 Kip (1225 kN) / ±7.25” (185 mm)	168
3	1300 Kip (5800 kN)/ ±7.5” (190 mm)	12	4 –PFD Type-3 325 Kip (1450 kN) / ±7.5” (190 mm)	48
4	1950 Kip (8700kN) / ±5.5” (140 mm)	32	6 –PFD Type-4 325Kip (1450)kN / 5.5” (140 mm)	192

Assembly of group of PFD units, called the Mega PFD, have the following advantages over single unit Mega Pall Friction Damper:

1. Easy handling in shop and transportation.
2. Savings as there is no need to upgrade existing equipment for manufacturing and testing.
3. Assembly work does not require skilled technicians and can be economically done by steel contractor.
4. The Surface área of the group of damper units is 2-4 times bigger than a single damper of equal capacity. Therefore, more heat is disposed off in radiation, resulting in less rise in temperatue for better performance.

2.2 Testing**:**

Prototype and Production testing was done in accordance with Standard ASCE/SEI 7-2010, Structures with Damping Devices, Section 18.9 Testing. Dr S. Mirza, a senior professor at McGill University in Montreal was assigned to carry out tests independently and submit the test report.

2.2.1 Prototype Test:

Two prototypes of each type of PFD-2 275 Kip (1225 kN) /±7.25” (185 mm) and PFD-2 325 Kip (1450 kN) /±7.5” (190 mm) were tested. The prototypes to be tested were already preset to specified slip load by the manufacturer for at least 2 cycles of loading. The prototypes, were subjected to 5 fully reversed cycles at MCE displacement. The energy dissipation capacityof prototypes was fairly maintained over fully reversed cycles The variation in slip load and areas of hysteresis loops was +3% to +8%, specification allow ±15%.Maximum rise in temperature above room temperature was about 70° F. Later, the damper was moved to verify that full stroke lengh (1.3xMCE) has been provided. The

Dr. S. Mirza of McGill University at Montreal conducting Test
Dr. James Kelly of University of California at Berkeley, Witness.

Fig.-14- PDL Test Rig: Capacity 500 Kip /±10” (Typical) Testing of Pall Friction Dampers slipping motion was uniformally smooth; noiseless; without any stick-slip phenomenon.

On the completion of tests, the PFDs were carefully inspected and there were no signs of damage, breakage or yielding. The results were very satisfactory. Dr. Mirza submitted the test report to client and structural engineer.

2.2.2 Production Tests:

These tests are necessary to maintain quality control on production. Each PFD (100%) has been already preset to the specified design slip load by PDL. Before the shipment, Dr. S. Mirza, a senior profesor at McGill University was invited to conduct production control testing. He randomly picked up about 10% of PFDs from each batch and proof tested for 2 fully reversed cycles at MCE displacements. The results were very satisfactory. The professor submited the production control test report to the client, project structural engineers and PDL.

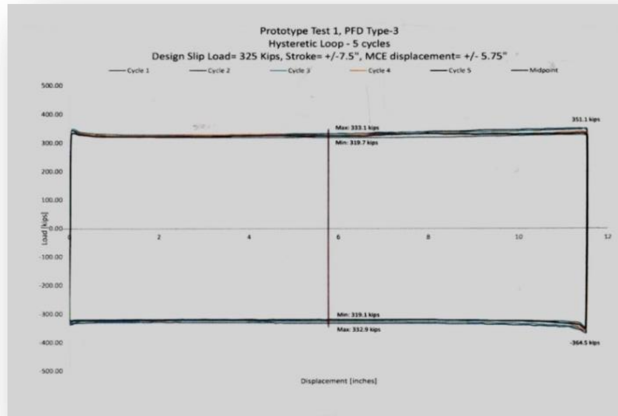


Fig.- 15- Hysteresis Loop of Prototype Test PFD Type-3, 325 Kip/±7.5”

2.3 Quality Control

At PDL, very strict quality contol is exercised at every stage from purchase of materials, production, testing and packing for delivery. All tested and inspected PFDs have a serial number and logo affixed. Fig.-16 shows the PFDs laid out for inspection of painting.

Fig.-16- PFDs laid out after painting for inspection

2.4 Installation of PFD Assemblies

Installation of PFD assemblies in the steel bracing was done by the steel contractor. Fig.-17 shows PFD Assembly-4 (1950 Kip) in chevron type bracing on two floors to form a cross brace pattern. These PFDs are on the interior and exposed to view. Fig.-18 shows PFD Assem0bly-2 (1100 Kip) and 3 (1300 Kip) in a single diagonal brace spanning over two floors. The brace in Fig.-19 is continuation of brace shown in Fig.-18. Bracing in Fig.-18 and 19 are on 4 exterior elevations and exposed to view. These pictures are during construction, before the PFD assemblies were painted.

Fig.-17. Assembly-4 in chevron brace on two floors form X- brace pattern.

Fig.-18. PFD Assembly-3 in diagonal-brace spanning over 2 floors.

Fig.-19. This brace is continuation of brace in Fig. 18, serves 2 floors.

MEGA PALL FRICTION DAMPERS DURING CONSTRUCTION (UN PAINTED)

2.5 Conclusion

The use of Pall Friction Dampers has shown to provide a practical, economical and effective approach for the seismic control of new construction and retrofit of existing buildings. With the emergence of this technology, it has now become economically feasible to make performance-based design of buildings for safety of modern buildings, contents and occupants.

The low cost and maintenance free characteristics of Pall Friction Dampers suggest wide application throughout the world for better and safer buildings

2.6 Acknowledgements

The author gratefully acknowledges the encouragement and cooperation of the project architects and project structural engineers. Without their support, the implementation of PFD technology in this project was not possible. Special thanks to Dr. Saeed Towfighi, Senior V.P, WSP Group, for his useful comments and suggestions in the making of Mega Pall friction damper for the project. Cooperation of Corey Steel is greatly appreciated.

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