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ASPECTS RELATED TO FLUID VISCOUS DISSIPATION DEVICES USED FOR SEISMIC PROTECTION OF STRUCTURES

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Abstract: *A seismic dissipation device working on fluid is presented as a fluid viscous damper (FVD), a constructive type of energy dissipation device used in civil engineering to protect structures (such as buildings and bridges) from the destructive effects of seismic forces. These devices absorb and dissipate energy generated during earthquakes, reducing the forces and deformations transferred to the structure. The seismic dissipation devices convert the kinetic energy from piston translational motion into heat through fluid viscosity enhancing an effective structural damping and seismic response during the earthquake ground motion. The linear fluid viscous device provides a directly proportional damping force to the relative velocity across the damper, being commonly used in structures where a uniform damping response is required, while nonlinear fluid viscous dampers exhibit a damping force that follows a nonlinear behaviour with velocity achieving greater damping at lower velocities being tuned for specific seismic response needs.*
These devices absorb a significant amount of seismic energy, reducing the forces transmitted to the structural elements, limiting the oscillations amplitude and control the structure displacement during an earthquake, reducing the risk of damage to non-structural components like walls, partitions, and equipment.
The fluid viscous devices can be used for existing buildings and bridges retrofit, providing an effective way to upgrade seismic resistance without significant structural alterations, providing a long service life and typically minimal maintenance requirements since they do not rely on other mechanical components. A numerical analysis was conducted based on the NEWMARK-Beta method for highlighting the operational capabilities of a fluid viscous device being presented results for displacement, velocity and acceleration registered and also the force-displacement loop for different velocity coefficient values. The obtained results illustrate the effectiveness of fluid viscous dampers in dissipating energy and reducing seismic-induced responses in structures.

Keywords: *Hydraulic actuation, dissipation device, fluid flow, operational parameters, numerical analysis*

1. Introduction

Fluid viscous dampers rely on the resistance generated by fluid flow through a small orifice or valve within a cylinder. The core components of an FVD are represented by the main cylinder which houses a piston and contains the working fluid. The piston as the movable component inside the cylinder forces fluid to circulate through small orifices made inside the piston head. The orifices or valves maintain control on the fluid flow and generates resistance during fluid movement.
The working fluid is usually silicone or oil, a high-viscosity fluid that resists motion and dissipates energy by generating heat.
During an earthquake or other dynamic event, the structure undergoes oscillatory motion. This motion is transferred to the damper, where it causes relative movement between the damper's piston and cylinder.
As the piston moves within the cylinder, it forces the fluid to flow through specially designed valves or small orifices while further this flow creates resistance to motion. The size of the orifices controls the amount of resistance, and hence, the amount of energy dissipation.
The resistance to fluid flow through the orifice converts kinetic energy (from the earthquake motion) into heat within the fluid. The energy is dissipated through this conversion, reducing the amount of energy transmitted to the structure. The generated heat is harmlessly dissipated to the surrounding environment.
Fluid viscous dampers can be designed to provide non-linear damping, meaning the damping force can be proportional to velocity raised to a power. This gives designers flexibility to adjust the damping properties to match the dynamic behaviour of a structure. For instance, for smaller

vibrations, the damping force may be lower, while for larger, more destructive vibrations, the force increases significantly.
The force exerted by an FVD is proportional to the velocity of motion and this contrasts with other damping devices like friction dampers, where the force is displacement-dependent.
FVDs do not change the stiffness of the structure because the damping force depends on velocity and not displacement. This characteristic makes them suitable for both retrofitting existing buildings and for new structures where altering the stiffness is not desirable.
The performance of FVDs can be easily tuned by changing the orifice size, fluid viscosity, or piston design, allowing engineers to control the level of energy dissipation.
Fluid viscous dampers are commonly installed in both new and existing buildings to mitigate seismic forces. They can be incorporated in the bracing systems of structures, reducing the lateral drift and increasing overall stability during earthquakes.
In bridge structures, FVDs are used to control the displacement and forces on bridge piers during seismic events. They allow controlled movements of bridge decks while dissipating energy.
In tall buildings or slender structures, fluid viscous dampers can be part of a TMD system to reduce oscillations caused by wind or earthquakes.
Advantages are related to high efficiency in operation while FVDs dissipate a significant amount of seismic energy, reducing the demands on the structural members. Since the internal components (fluid and piston) are enclosed, they generally require minimal maintenance and the absence of moving parts prone to wear makes fluid viscous dampers highly reliable for long-term seismic protection, while fluid viscous dampers are able to stabilize the building against both wind and seismic forces.
These hydraulic devices are protecting the structures from earthquake damage by dissipating the kinetic energy induced by ground motion, reducing structural vibrations without increasing stiffness. They are highly effective in both new constructions and retrofits, providing a reliable and low-maintenance solution for seismic protection.
The basic parameters and the operating principle are described in this work for fluid viscous dissipation device. A mathematical model describing the operation is also presented, as well as a numerical approach in order to highlight the operating characteristics.

2. Construction principle and materials used for fluid viscous device

The construction process of fluid viscous damper (FVD) involves several stages and specific materials used in order to achieve energy dissipation through fluid viscosity properties.
The main component of a fluid viscous damper is represented by the cylinder, which houses the piston and the viscous working fluid. It is typically made from high-strength materials, such as steel, to withstand the forces exerted during operation. Inside the cylinder is positioned the piston that divides the fluid in two chambers and generates damping force as it moves back and forth. The piston is designed with orifices or channels through which the working fluid flows, being controlled the fluid flow between the two chambers on either side of the piston. The size and shape of the orifices are critical for determining the damping characteristics.
The fluid inside the cylinder is usually a silicone-based liquid, which provides resistance to the piston's movement. The fluid's viscosity property determines the damping force and needs to remain stable across a range of temperatures.
Special seals and bearings are used to prevent fluid leakage and ensure smooth movement of the piston within the cylinder, while high-quality sealing solutions are essential in order to maintain damper performance over time.
The damper device ends are fitted with connections to attach the device securely to the isolated structure, allowing the damper to be connected to braces, frames, or other structural elements.
Regarding the materials used cylinder and piston are typically made from high-strength steel or stainless steel that handle the stresses during seismic events and prevent deformation [1-7].
The viscous working fluid is usually silicone oil because of its stable viscosity over a wide temperature range, low volatility, and excellent thermal properties.

The sealing is usually made from elastomeric materials, such as VITON (fluoro-elastomers that can retain their flexibility, shape, sealing well even when are exposed to chemical solutions and high temperatures values), or other high-performance rubbers in order to ensure tight sealing and resistance to wear and chemical degradation.
The bearings are often made from low-friction materials like Teflon or bronze, which allow the piston to move smoothly within the cylinder.
FVDs are installed in strategic locations within buildings or bridges where they can most effectively reduce seismic forces. Typical installation locations are within buildings as diagonally braces across structural elements in order to absorb the lateral forces, between floors to reduce inter-story drift by controlling relative motion between floors, or expansion joints within bridges where FVDs are used to limit the movement of expansion joints during seismic events.
During construction, FVDs are subject to strict quality control to ensure consistent performance, especially under varying temperature conditions.
While FVDs are generally low maintenance, periodic inspections are performed to check for fluid leakage, seal integrity and overall structural condition.
The construction of fluid viscous dampers involves precision engineering, high-quality materials, and rigorous testing to ensure effective seismic energy dissipation. By combining a carefully designed piston, a stable viscous fluid and a robust cylinder, FVDs can effectively reduce structural vibrations and protect buildings and bridges from seismic damage. Proper installation activity and periodical maintenance are important in order to maximize the longevity performance efficiency of these protective devices [8-11].

3. Mathematical model for fluid viscous device

The mathematical model for a fluid viscous damper (FVD) is presented in order to describe the device behaviour in dissipating energy during dynamic events such as earthquakes. The damping force generated by fluid viscous damper depends on the relative velocity of the motion across the damper, as well as the properties of the fluid and damper design.
The basic damper mathematical model is given by the generated response force expressed as:

$$F_d = c \cdot v^a \tag{1}$$

where:

F_d - the damping force;
c - the damping coefficient, represents the damper's resistance to motion, determined by the fluid's properties and the damper's configuration;
v - the relative velocity of the damper piston;
a - the velocity exponent, typically between 0.5 and 1, indicating the nonlinearity of the damper's response.
For the device linear model when *a=1*, the damping force is directly proportional to the velocity, while the equation simplifies to:

$$F_d = c \cdot v \tag{2}$$

In this case, the damper is considered linear, and the damping force varies linearly with the velocity.
For the nonlinear model, when *0<a<1*, the damping force varies nonlinearly with velocity and this is commonly used in structural applications because it allows for higher damping forces at lower velocities and can be tuned to achieve specific damping characteristics.
The energy dissipated by the fluid viscous damper is related to the mechanical work done by the damping force over the displacement. The power dissipated at any given time can be calculated as:

$$P_d = F_d \cdot v = c \cdot v^{a+1} \quad (3)$$

where:
P_d - the dissipation power.
The total dissipated energy amount over a time interval can be obtained by integrating the power dissipation over time.
The equivalent viscous damping characteristics for FVD, in structural dynamics is introduced the equivalent viscous damping ratio ς_{vd} as the damping characteristics of the fluid viscous damper in terms of an equivalent linear system. The equivalent damping ratio can be calculated from the damping force characteristics as:

$$\varsigma_{vd} = \frac{c}{2m\omega} \quad (4)$$

where:
m - the equivalent system mass;
ω - the angular vibration frequency.
The damping force in structural system in the context of a dynamic loading such as earthquake motion, the equation of motion for a mass-spring-damper system incorporating a fluid viscous damper can be written as:

$$\begin{gathered} F = m\ddot{x} + c\dot{x} + kx \\ F = m\ddot{x} + c\dot{x}^a + kx \end{gathered} \quad (5)$$

where:

m - system mass;
$\ddot{x}$ - mass acceleration;
c - is the damping coefficient of the fluid viscous damper (linear model);
$\dot{x}$ - velocity (displacement rate of change);
k - the device stiffness;
x - displacement;
F - external force acting on the system.

For nonlinear dampers, the damping term is considered as ($c\dot{x}^a$).
The further modelling considerations are related to temperature dependences while the fluid viscosity changes with temperature, affecting the damping coefficient (c) and the frequency dependence as the damper effectiveness changes with the vibrations frequency, especially for highly nonlinear dampers [1-5, 12].

4. Numerical analysis for fluid viscous device operation

The numerical analysis for a fluid viscous damper (FVD) operation involves simulating of linear and nonlinear behaviour under dynamic conditions in order to predict its effectiveness in dissipating energy in vibrations subjected structures during seismic events. The process typically involves solving the equations of motion that govern the structure's response, incorporating the characteristics of the fluid viscous damper.
Performing a numerical analysis for fluid viscous damper operation implies the proper formulation of the problem necessary to analyze a structural system equipped with a fluid viscous damper and further formulation of the governing equation of motion. For a single-degree-of-freedom (SDOF) system with mass *m*, damping *c*, stiffness *k* and an external force *F,* the equations of motion for the linear and nonlinear model can be written as:

$$F(t) = m\ddot{x}(t) + c\dot{x}(t) + kx(t)$$
$$F(t) = m\ddot{x}(t) + c\left|\dot{x}(t)\right|^{a-1} + kx(t) \tag{6}$$

where:

$x(t)$ - mass displacement as a function of time;

$\dot{x}(t)$, $\ddot{x}(t)$ - velocity and acceleration, respectively;

$F(t)$ - external force applied to the system during earthquake ground motion.

To perform the numerical analysis, the time domain is discretized into small time steps of *Δt*. The time intervals are represented as $t_0,\ t_1, \ldots.., t_n$, where $t_{i+1} = t_i + \Delta t$.
The numerical integration method used to solve the differential equation of motion is represented by NEWMARK-Beta method for solving equations of motion in structural dynamics [1-7, 13].
The selected method makes use of the following iterative relations in order to update displacement and velocity at each time step:

$$x_{i+1} = x_i + \dot{x}_i \cdot \Delta t + \ddot{x} \cdot \frac{\Delta t^2}{2}$$
$$\dot{x}_{i+1} = \dot{x}_i + \ddot{x} \cdot \Delta t \tag{7}$$
$$\ddot{x}_{i+1} = \frac{1}{m}\left[F_{,i+1} - c\left|\dot{x}_{i+1}\right|^{a-1}\dot{x}_{i+1} - k \cdot x_{i+1}\right]$$

The displacement values, velocity and acceleration are updated iteratively for each time step.

Table 1: Fluid viscous device parameters for analysis

Crt. No.	Parameter type	Unit	Values
1.	Mass	(kg)	10000
2.	Stiffness	(N/m)	50000
3.	Damping coefficient	(Ns/m)	10000
4.	Velocity exponent for nonlinear damping	-	0.6/0.7/0.8/0.9
5.	Amplitude of motion	(m)	0.5
6.	Frequency of oscillation	(Hz)	0.5
7.	Total simulation time	(s)	10.0

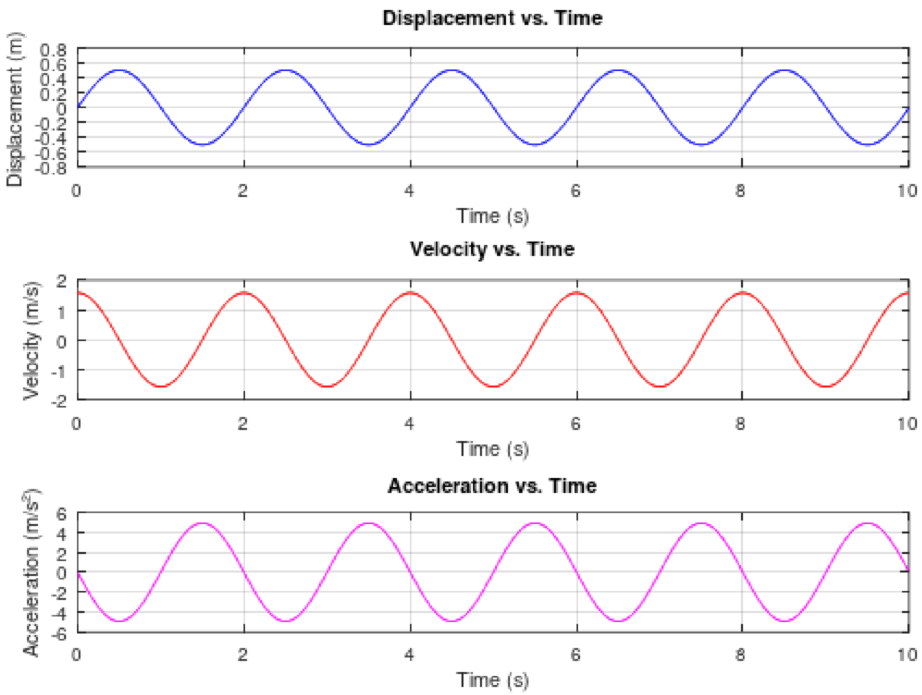

Fig. 1. Diagrams for displacement, velocity and acceleration

The results for displacement, velocity, and acceleration presented in figure 1 show the expected sinusoidal patterns, reflecting harmonic motion. The results indicate that the FVD is effective in controlling both displacement and acceleration, which is crucial for reducing structural responses during seismic events.

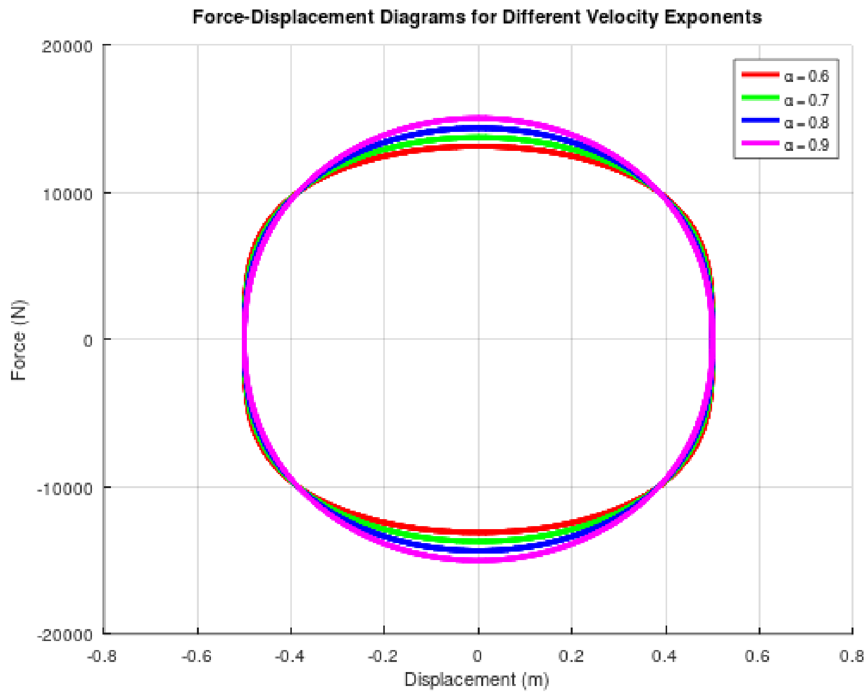

Fig. 2. Force displaments diagram for different velocity exponents values

The force-displacement diagrams demonstrate the characteristic hysteresis loops of devices, indicating energy dissipation during cyclic loading, while the area enclosed by the loops corresponds to the amount of energy dissipated per cycle.
The numerical analysis results confirm that for different velocity exponents, the shape of the force-displacement loops change (figure 2). Lower values (0.6) resulted in flatter hysteresis loops, indicating less force generation for a given velocity. In contrast, higher values (0.9) showed steeper loops, suggesting higher energy dissipation and greater damping forces.
The use of non-linear damping allows a more realistic representation of FVD behaviour under different velocities. The non-linearity helps to model the actual physical characteristics of fluid dampers, where the damping force does not necessarily increase linearly with velocity.
With velocity coefficients less than 1, the device shows a reduced sensitivity to high velocities, which could be beneficial for preventing excessive force transmission in structures during strong seismic events.

5. Conclusions

Based on the simulation results obtained for the fluid viscous damper (FVD) operating under cyclic motion, can be highlighted the device's behaviour and effectiveness in seismic protection of structures where are mounted.
The amount of energy dissipated over time, calculated through numerical integration, confirmed that the device effectively reduces the mechanical energy transmitted to the structure.
The energy dissipation is vital for minimizing the amplitude of structural vibrations and protecting the building from damage.
Fluid viscous dampers, with their ability to provide significant energy dissipation, are well-suited for seismic protection of structures.
The non-linear damping characteristics offer flexibility in design, allowing the improvement of damping behaviour to meet specific performance requirements.
The use of varying damping coefficients and velocity exponents can be adjusted based on the expected ground motion characteristics, ensuring optimal performance in different seismic scenarios.
The numerical analysis using the NEWMARK-Beta method and subsequent obtained results for force-displacement, velocity and acceleration illustrates the effectiveness of fluid viscous dampers in dissipating energy and reducing seismic-induced responses in structures.
The results confirm the value of non-linear damping models in capturing the actual behaviour of FVDs under dynamic loading.
The ability to adjust the damping parameters provides a versatile approach for designing damping systems for mounting in specific structures and meeting the anti-seismic protection demands.

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