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Title: New Applications of High Force to Volume (HF2V) Devices

Researchers: Prof JG Chase, A/Prof GA MacRae and Dr GW Rodgers

University of Canterbury

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Introduction and Background Abstract:
This research sought to extend and enhance the performance and applicability of novel high-force-to-volume (HF2V) energy dissipation devices. These HF2V devices comprise a bulged shaft and a cylinder filled with lead. Lead is used due to its ability to re-crystallise after extrusion past the (moving) bulge. This offers repeatable and damage free energy dissipation [1].

These devices have been shown to enable damage-free structural steel and unbonded prestressed concrete connections [2-5]. They also offer a great deal of potential for in numerous other applications. In particular, the development of smaller, lower force, devices greatly expands possible applications to use in a range of industrial plant equipment and essential services (e.g. refineries, water treatment plants, heavy equipment), as well as (potentially) houses/light structures. All have lower seismic mass and require lower-force, higher velocity devices that have not been proven in prior studies. Creating such devices would enable:

a) Better design of HF2V devices to exact specifications for all potential implementation scenarios. These could be tested at higher velocities than has been carried out with larger 100-500kN capacity devices
b) A wider range of new applications, creating industry applications to further prove the efficacy of these devices without first committing to use in large, critical building infrastructure. This provides a minimal risk route to regular use.
c) Enable applications for damage free houses/housing of the type insured by EQC.

This project would see the design, development, and experimental testing of 5-8 new devices of varying designs to greatly expand possible applications, provide a route to regular use that has less risk to the building industry, and potentially lead to novel housing and small structure (e.g. milk sheds etc) applications.

These lower force devices will also enable higher velocity testing, providing additional device characterisation and improving design relationships. The overall objectives are to:

⇒ Expand the range and capability of these devices to extend their application space and thus offer them the opportunity to prove their potential in applications less risky than large, critical infrastructure/buildings
⇒ Create (in doing so) the knowledge and experimental results to very accurately define the mechanics and dynamics that characterise HF2V devices so they can be very accurately designed to any force/capacity level, and thus accurately designed for any specific application requirements.

Overall this work built on very successful research outcomes to date in this area, and greatly expands the potential future uses of these devices and creates a pathway into industrial use to prove the concept before committing to application in large, critical infrastructure.

Thus, the **Overall Project Goals** were defined:

- Develop **smaller devices** with lower peak forces for applications with smaller seismic mass, including houses, milking sheds and similar small structures. These applications would also be applicable to any low seismic mass application, such as “non-structural” infra-structure at refining or water treatment plants, as well as for isolating critical manufacturing or hospital services within a larger structure.
- Experiments to **better predict and understand device performance** at higher and seismically likely velocities, which can only be done with smaller capacity devices due to the limits of existing dynamic test equipment.

SUMMARY OF WORK DONE AND RESULTS:

Objective No. 1

Objective Title: Develop Smaller Devices (Device Development)
Objective Achieved? Yes

Results and Outcomes: the main results include the characterisation of the capabilities and performance of several devices in the sub-100kN capacity range. In particular devices with predicted force capacities of 30-50kN were designed and tested both quasi-statically and dynamically. The testing showed that such devices are feasible. However, dynamics and force capacity are dominated at low total device forces by:

- Friction
- Pre-Stress applied

Friction between lead and shaft dominates force capacity in these devices. In contrast, larger devices are dominated by a shear force capacity of moving the lead. The pre-stress applied to the device is also a factor and the more greatly the lead is compressed in a very small and low force capacity device the greater the outcome force (all else equal). This latter force is not a factor for larger, higher force capacity devices.

Finally, a novel new approach was tried for all these devices and tests. In particular, an “internal” or “inward” bulge was tested in contrast to the normal “outward” bulge with larger diameter than the device shaft. These inward bulged shafts performed equally well. In addition, they had slightly lower force capacity than outward bulge designs, making it easier to achieve lower capacity devices.

Hence, low force capacity devices are feasible; however their design is highly, or more greatly, sensitive to design and construction factors. A novel new design for such devices was also created and tested that better enabled lower force capacity devices as well as expanding the possibilities for these devices and their design for specific needs or force/dissipation levels.

Outputs: Main outputs include:

- Published: 2 full conference papers [6, 7], 1 full journal article [8]
- In-Review: 1 conference papers, 1 journal articles
- These articles fully document all the details and results.
- See References for full list

End-Users:

- Structural Engineering and consulting firms, NZTA / ONTRACK, the SESOC, and local authorities have all seen this work and have access to results and further information on inquiry.

Objective No. 2

Objective Experiments to better predict and understand device performance
Objective Achieved? Yes

Results and Outcomes: the main result is the creation of models that better predict the outcome force capacity of HF2V device designs. Both static and dynamic forces are predicted based on the results of the experiments and data from Objective 1. More generally and overall, the methodological approach can also be used for any similar new device design or approach as well, providing an overall design framework and thus an industry end-user outcome to ease eventual application of these devices.

Outputs: Main outputs include:

- Published: 4 full conference papers [9-12], 1 full journal article [8]
- In-Review: 2 conference papers, 1 journal articles
- These articles fully document all the details and results.
- See References for full list

End-Users:

- Structural Engineering and consulting firms, NZTA / ONTRACK, the SESOC, and local authorities have all seen this work and have access to results and further information on inquiry.
- Standards NZ (for use in creation or update of standards for lifelines)

SUMMARY

Conclusions & Recommendations: This research and its main outcomes enable low or no damage ("Damage-Free") infrastructure and building designs as well as retrofit. They utilise emerging structural technologies and devices derived from NZ innovation and research, which were extended to novel new types in this research. Thus, overall, this research has enabled low force capacity devices and new (low force) device designs, which are shown to clearly be technically and economically feasible. Hence, the research has opened significant new design and use possibilities to enable these devices to reach regular use in design via a range of possible application spaces.

The use of these devices, based on the experimental and analytical research results presented should be taken up by end users and implemented in emerging, updated design standards from Standards NZ. This uptake could, in future, create significant added structural and lifeline resilience for NZ cities and communities in the presence of significant seismic risk.

References: All references are available on request (or / and as they appear)

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