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BIOINSPIRATION AND ANALYSIS OF MULTILEVEL ROCKING CORES

Mark GRIGORIAN
Senior Structural Engineer, MGA Struct. Eng. Inc., 111 N. Jackson St. Glendale, CA 91206, US
markarjan@aol.com

Armen MINASSIAN
Advisor to the Chairman of Urban Development Committee, Republic of Armenia
armen.minassian@gmail.com

Hadiseh MOHAMMADI
M.Sc. Graduate, IIEES, Tehran, Iran
hadis_mohammadi11@yahoo.com

Mozhgan KAMIZI
M.Sc. Graduate, Department of Civil Engineering, Faculty of Engineering, Golestan University, Gorgan, Iran
m.kamizi95@stu.gu.ac.ir

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The human spine is a highly complex, multifunctional bio-electromechanical system that has been evolved to perform fundamental biological tasks needed to maintain life as we know it. It is a naturally optimized, three dimensional load bearing structure that is capable of withstanding combined gravitational, torsional, and bending effects at any inclination with respect to any fixed line of reference (Benzel, 1995). As a highly precise, self-aligning configuration the spine is also capable of damping dynamic effects due to normal locomotion and accidental impact (Roberts & Chan, 1970). In the physical sense, the word ‘structure’ implies arrangement of material parts in a purposeful manner and as such may apply to the human spine, the universe as well as earthquake resisting frameworks. In the present context, structure is referred to manmade load bearing engineering frameworks. While there are countless numbers of natural systems and materials, there are only limited numbers of manmade earthquake resisting archetypes, consequently not all desirable features of natural systems could be incorporated into the design of all known forms of engineering structures. The purpose of the current article is to show that an understanding of the structural performance of the human spine can enhance the physical response of earthquake resisting archetypes in general and that of MLRCs in particular. It is also possible that the analogous performances of the natural and manmade structures may help explain the structural response of natural spines to similar loading scenarios. Design methodology transfer from natural objects to manmade frameworks is not new and has been successfully accomplished, amongst others by the senior author (Grigorian, 2014a, 2014b). Here, the spinal column is looked upon an inspirational model for developing efficient earthquake resisting systems with a view to damage control and self-alignment. The most applicable components of the spine, from a structural engineering point of view, that may be utilized as the constitutive elements of MLRCs or similar systems can be listed as follows;

1. The vertebrae that compose the spinal column. The bony vertebrae are mimicked as the inter-story solid cores of Figure 1, and constitute the building blocks of the proposed MLRC system of Figures 2-c and 4-c.
2. The intervertebral discs that prevent contact between vertebrae and act as natural shock absorbers due to normal locomotion. These jelly like cushions are replicated with energy absorbing devices such as resilient slip friction joints, elasto-plastic yielding parts or similar dampers as depicted in Figure 3-c.
3. The facet joints that allow controlled articulation and load transfer between adjacent vertebrae. The mechanical functions of the facet joints are imitated by ordinary pin and socket joints as illustrated in Figure 1.
4. The rib facets that hold the entire rib cage and its attachments together. The facets are replaced with short, relatively rigid link beams that connect the gravity structure to the MLRC.

5. The ligaments and tendons, that stabilize, realign and hold the spinal column together. These symmetrically positioned bands of toughened tissues are replaced with short lengths of slightly preloaded, axially extensible ties, rods or similar members, Figures 1-a and 1-f.

The spinal column is a three dimensional system. However, its bioinspired counterpart was designed as a two dimensional structure in order to avoid theoretical complications as earthquake resisting parts of commonly available building systems.

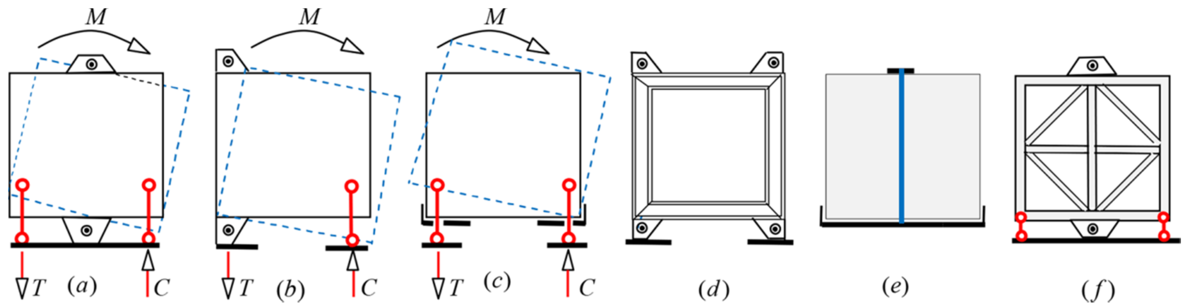

Figure 1. (a) Center pivot rocking, (b) Side pivot rocking, (c) Stepping, (d) Racking system, (e) Solid section, (f) Braced frame.

This article presents a simple analogy, with practical applications, between the human spine and Multilevel Rocking Cores (MLRCs) under similar loading conditions. The use of energy dissipating rocking cores in general and Multilevel Rocking Cores (MLRC) in particular is a relatively new concept for reducing earthquake damage in new and existing buildings. The literature on the subject is rather scant. There are neither official guidelines nor educational materials for practical design of MLRCs. The first step towards rational design of MLRCs is to understand their elastic state static/dynamic behavior as part of a gravity and/or earthquake resisting system. The purpose of the current paper is not to reiterate the merits of various rocking systems, but to provide reliable formulae for the preliminary design of simple MLRCs. Suffice to note that the multitude of gap movements in MLRCs results in increased damping and elongated periods of vibrations. Several parametric examples have been provided to demonstrate the applications, the validity and the simplicity of the proposed solutions. All solutions are exact within the bounds of the theoretical assumptions. All results have been verified by independent computer analysis.

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