

# Seismic behavior of recycled plastic lumber walls: An experimental and analytical research

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## ABSTRACT

Recycled Plastic Lumber (RPL) is a wood-like material made from recycled plastics that aims to diminish the environmental pollution resulting from plastic wastes. This material is used in different kinds of nonstructural and structural applications. Recently, RPL has been proposed as a suitable material to develop structural walls that comprise the seismic resistant system of housings, in order to lessen the housing deficiency. This article presents the results drawn from an experimental campaign carried out over three full-scale RPL walls, which were tested under cycling loading conditions to determine structural parameters such as strength, hysteretic behavior, ductility, energy dissipation, equivalent damping and characteristic failure modes of the RPL walls, which are necessary to design and to assess seismically the housings. Finally, a multilinear hysteretic model capable of simulating the nonlinear dynamic behavior exhibited by RPL walls was implemented, in order to simulate and to assess the seismic behavior of them under strong and destructive real earthquakes.

## 1. Introduction

The use of residues resulting from the human activity is currently a potential and sustainable source of materials for the building sector, particularly for the housing development. Plastic is a material commonly used in the human activities, that is almost impossible to break it down by natural processes on account of its strength and durability. In the last 65 years, 8.3 billion tonnes of virgin plastic have been produced of which 6.3 billion tonnes of plastic wastes have been generated; Of this value, roughly 9% is recycled, 12% is incinerated, and 79% is in a landfill or in the natural environment [1]. It is beyond dispute that from the civil engineering and others branches of knowledge, it is required to implement a sustainable use of the plastic wastes in order to protect the natural environment and to obtain useful materials. Different researchers, standards societies, universities, governs and building companies, have joined forces both to reduce the pollution of plastic on the planet and to make the plastic a suitable material for the building sector.

Recycled Plastic Lumber (RPL) is a wood-like material made from recycled plastic, used as a substitute for the raw materials in structures made from concrete, metals, and wood. RPL needs a few chemical and industrial processes, and the current technology allows the correct separation and cleaning of its raw material. The manufacture of RPL allows making the most of large quantities of plastic wastes and

converting them into useful and durable products [2]. This material has shown be rot resistant and not be susceptible to the corrosion or insect attacks, assuring the durability [3]. Structural elements made of RPL have a nonhomogeneous cross-section due to the cooling process during extrusion; this feature together with the nonlinear nature of the material makes different its tension and compression behavior, and some mechanical properties are difficult to determine [4]. As a consequence, in order to characterize this material and to enable the market acceptance of RPL in structural and building applications, ASTM International has developed specifications and test methods standards [5–9]. In addition, from materials engineering, RPL has been studied to know its mechanical properties, such as density, elasticity modulus, compressive, flexural, shear and tensile strength [3,10,4,11], creep behavior [4,12], among others, that are important for the structural design.

The first applications of RPL were in urban furniture and in low-stress or non-critical load outdoor structures, such as picnic tables, park benches, trash receptacle covers, among others. With the satisfactory performance of these applications, RPL gained popularity and it was seen as a novel material for others applications, such as docks, boardwalks, and decks [2]. However, some of the first RPL decking structures sagged with time due to their low stiffness and their tendency to creep under its own weight [2]. As a consequence, manufacturers and structural designers learned to design these structures with lower stress on the elements, for example, decreasing the joist spacings and/or using

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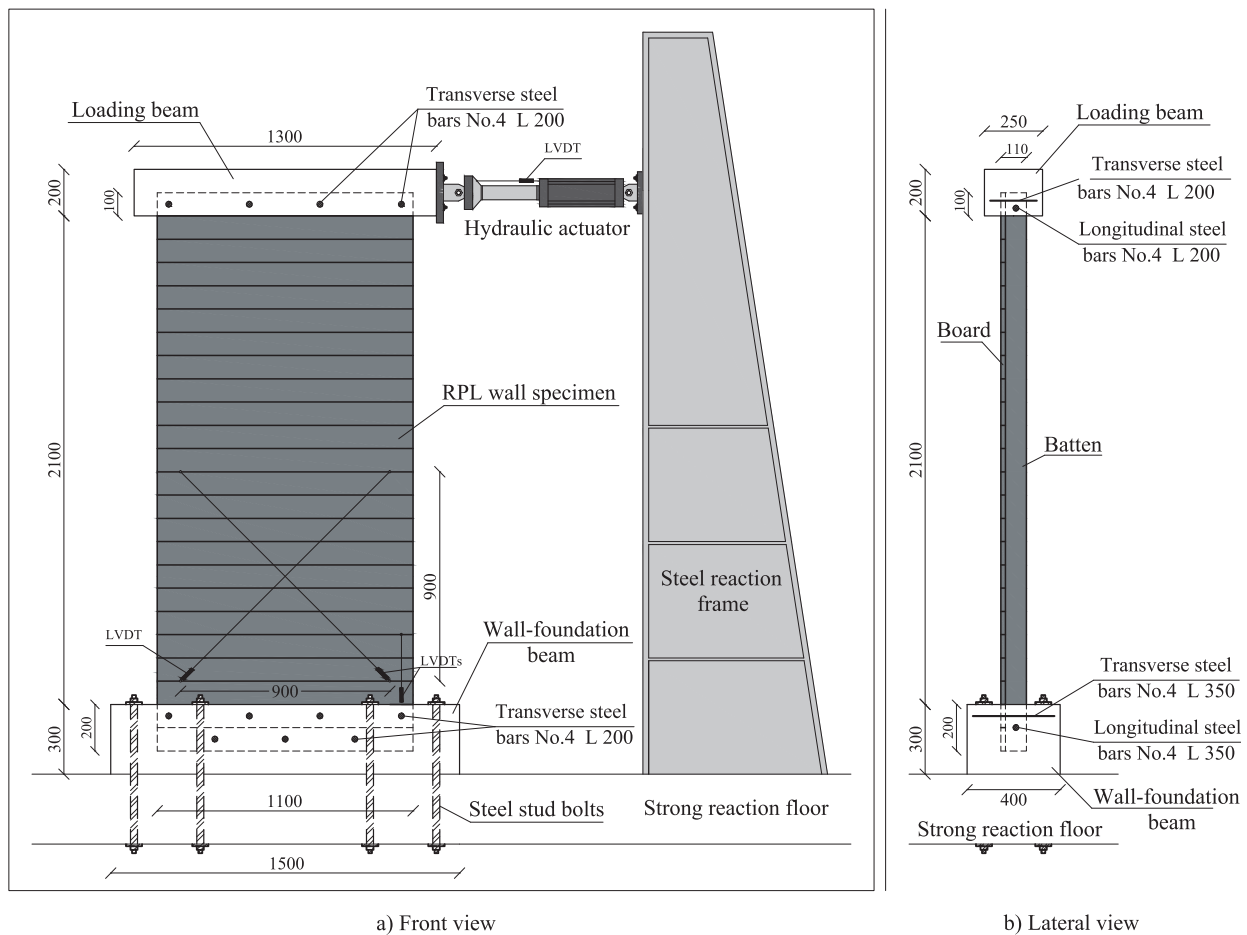


Fig. 1. Test setup and geometry of the RPL walls specimens (mm).

thicker deck boards, in order to reduce the time-dependent properties that change the overall shape of the elements [13]. Gradually, RPL started to be used in several structural applications where concrete, steel or wood, were the traditional material, such as joists, marine pilings, bridges (for military tanks, railroads and vehicular traffic), one and two-story housings, among others. In 2000, McLaren et al. [14] described and implemented laboratory tests to the connections and to the structural elements of the first recycled plastic bridge in the world made from a glass fiber reinforced recycled plastic lumber composite material, in order to evaluate and to verify the mechanical properties of RPL and the structural behavior of the bridge. In 2009, Chandra and Kim [15] described the first bridges of the world made from RPL; they showed that the use of the RPL in bridges had increased.

Recently, RPL has been investigated and implemented for the construction of housings of one and two-story [11,16], looking to diminish the housing deficiency and the accumulations of plastic wastes in the natural environment; in fact, some building companies and researchers have developed housing systems based RPL structural walls that define the structural system of seismic resistance [16,17]. Gulhane and Gulhane [11] developed analytical studies of housings built with precast RPL elements that allowed identifying some structural features, such as large horizontal displacements in the walls that formed the housings when they were subjected to seismic or wind loads. These displacements suggested doubling the thickness of the walls and using a hollow section in order to improve the structural behavior. Compression and flexural strength were not exceeded by the stress induced by seismic, wind or typical loads of use or occupancy of the housings, but care must be taken with the excessive lateral displacements respect to the height of the building. Moreover, they found that the RPL elements had a specific density of 2.2–2.8 times less than the masonry walls or concrete

elements, and a compressive strength of 25–26 MPa, which is more than the compressive strength of the masonry wall (1.8–2.9 MPa) and similar to concrete compressive strength (17–28 MPa). From the seismic-resistant engineering, the use of light and resistant materials constitutes a natural seismic-resistant system for any kind of building [18]; housings built of RPL could have a better seismic performance given its low density and high strength than those built of usual materials, such as those present in the earthquakes of Haiti 2010, Chile 2010, Nepal 2015, Ecuador 2016 and Mexico 2017. Hence, it is necessary to assess the behavior of the structural systems based RPL walls under cyclic loads that simulate the strong phase of an earthquake, in order to determine structural parameters, such as stiffness, lateral resistance, ductility, energy dissipation capacity and damping, which allow a reliable design of the housings [19].

The plan of this paper is as follows: first, laboratory tests on three full-scale walls were carried out in order to evaluate the hysteretic behavior, the strength, the energy dissipation capacity, damping, and failure modes of the RPL walls when subjected to cyclic loading conditions. Then, it is proposed a nonlinear dynamical model that is able to simulate the behavior exhibited by RPL walls under cyclic loading conditions. A multilinear hysteretic model [20] is used here. Later, an assessment of the seismic performance of the RPL walls when subjected to recent earthquakes using the proposed nonlinear dynamical model is performed. The paper ends with some conclusions.

## 2. Test specimens

### 2.1. Description of constituent elements

To manufacture RPL, the raw materials are sorted, cleaned and

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