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Short communication

Design of regular and shear-reinforced panel web beams for long-span construction

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ABSTRACT

The design of a 84-m-long 6.7-m-wide one-story residence built on an island off the coast of British Columbia, Canada, presented special timber engineering challenges. To use materials that can be easily transported in pieces and built on-site, panel web beams (PWBs) were developed as main structural components. Two types of PWBs were used. One is the regular PWB built with glulam members as the flanges, plywood panels as the web, and dimension lumber members as the stiffeners. The other is the shear-reinforced PWBs used in regions where design shear forces were excessive. The shear reinforcement consisted of metal sheet plates and steel plate stripes concealed inside the regular PWB. The perimeter steel plate stripes were connected to wood members using timber rivets. The use of both types of PWBs showed the possibility of designing and building wood composite members for long-span construction with small-size materials that can be easily transported to the site.

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1. Introduction

Wood is a conventional construction material with the advantage of light weight, low cost and easy fabrication. Wood and wood-based materials are considered to be environmental-friendly for building construction. The use of wood is attracting much attention from stakeholders who are seeking "green" solutions in construction practice.

Commercially available solid sawn timber has size limitations. Over the years, engineered wood products such as structural panels, glued laminated timber (glulam), structural composite lumber, wood I-beams, and wood trusses have been introduced in the market allowing large span structures to be built thus expanding the application of wood products in construction. The panel web beam (PWB) is a type of glued composite building component using wood sheathing panels and lumber or glued-laminated timber [1]. The sheathing panels can be plywood or oriented strand board. PWBs also have the name of glued plywood–lumber beams in the USA [2]. In PWBs, tensile and compressive strength from the flanges develops bending moment, while sheathing panels act as the web to carry shear force. Vertical stiffeners between flanges are commonly required to transmit loads and provide stability for web panels. The cross-section of PWBs is typically in box-shape or I-shape, as indicated in Fig. 1. Other shapes can also be used, depending on materials, dimensions and applications [2].

The width-to-depth ratio of the PWBs is relatively small in order to develop sufficient bending strength and stiffness. The small width-to-depth ratio also brings potential stability issues for the PWBs, which commonly require lateral braces at least on the compressive edge of the PWBs. Adhesives are used to glue all webs and flanges together to develop the composition action. Nails and other mechanical fasteners may be used to apply pressure to cure the adhesive. But these mechanical fasteners traditionally do not expect to develop shear stresses for composite action. The web panel joints also rely on adhesives to transfer shear loads. The integrity of PWBs relies on the gluing bond.

This paper introduces the application of PWBs in a residential construction on a remote island. Two types of PWBs were used in that project. One is the conventional PWB using glulam and plywood panels. The other is a non-conventional PWB that was reinforced with metal plates to develop strong shear strength. A discussion about the design, fabrication and construction issues was also presented.

2. Site information

The project involves the design and construction of a one-story residential building on Saltspring Island off the west coast of British Columbia (BC), Canada. The local climate condition is moderate with typical features of islands in that region. The average temperatures in January and July are about 3 °C (37 °F) and 18 °C (64 °F), respectively. The design roof snow load for this residential building

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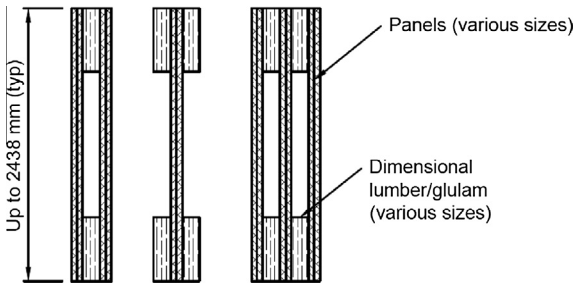

Fig. 1. Typical panel web beams.

is 1.4 kPa (30 psf), as specified by the National Building Code of Canada [3]. The local community has long been known as a special place in BC where a large number of artists, sculptors and musicians reside.

3. Building layout

The one-story house was built on a farm near the seaside of the island. It has a footprint of 84 m × 6.7 m (276 ft × 22 ft). The height of the structure is 4.2 m (14 ft) with a typical ceiling height of 3.6 m (12 ft). The house is divided into two wings by a 9.4 m (31 ft) wide breeze way. The main wing is 45 m (150 ft) long to the west and the guest wing is 14 m (45 ft) long to the east. The two wings were structurally connected at the roof level. Both ends of the building have a roof overhang, which is cantilevered over 9.8 m (32 ft) at one end and 8.5 m (28 ft) at the other. To maximize the seaside view, a large glass sliding door, 22 m (70 ft) wide, was placed in the middle of the north elevation (Fig. 2) [4].

To minimize importing structural fill to raise the foundation to a desired elevation, the main floor was constructed as a suspended concrete slab with foundation walls. Above the main floor was primary wood frame construction consisting of 140 mm (5-1/2″) wood bearing walls, and built-up and glulam posts. Several hollow steel structural sections were introduced in locations where minimum spatial presence was required. The lateral stability of the structure was provided by concrete fireplace walls and wood frame shear walls. The roof framing consisted of 12.5 mm (1/2 in.) plywood sheathing and 38 mm × 286 mm (nominal 2 × 12) joists at 406 mm (16 in.) on center. Glulam and laminated veneer lumber members were used as edge beams for smaller spans.

PWBs were developed for the large spans where glulam beams were not economical or practical for the site. The base materials of the PWBs can be easily transported in pieces and built-up on the site. The built-up process integrated structural members by using gluing and mechanical connections. With the appropriate choice of webs and flanges, the desired strength capacity and stiffness of PWBs were able to be achieved. All PWBs were supported by wood and/or steel posts, which were assumed to be pin-connected. Therefore, a main span was required to counteract the loadings on a cantilever span.

4. Design and construction of regular PWBs

The dead load of roof assembly was estimated to be 0.72 kPa (15 psf), in addition to the self-weight of the beams and other main structural components. The longest beam had a span of 22 m (70 ft) over the sliding door with a tributary width of 3.4 m (11 ft). With a total beam height of 1829 mm (6 ft), the PWB utilized 130 mm × 304 mm (5-1/8 in. × 12 in.) glulam members as the top and bottom flanges. The flanges carry tension and compression forces to develop moment resistance under beam bending action. Douglas Fir-Larch (D.Fir-L) Grade 16c-E and 18t-E glulam members were specified as the top and bottom flanges, respectively, for simple beams. The webs consisted of two layers of 12.5 mm (1/2 in.) regular grade Douglas Fir plywood panels nailed-glued to the flanges on both sides. Dimension lumber of 38 mm × 140 mm (nominal 2 × 6) spaced at 610 mm (24 in.) on center was placed inside the web panels as stiffeners and nailing supports. The plywood panels were cut to a size of 1220 mm × 1829 mm (4 ft × 6 ft) to suit the beam depth. The vertical joints of two layers of plywood panels were staggered 610 mm (2 ft) and aligned with the nailing supports. Fig. 3 shows the elevation of the beam, in which the top and bottom flanges, the staggered plywood panels and the stiffeners are presented. The width of the glulam flanges (130 mm or 5-1/8 in.) is smaller than that of the stiffeners (140 mm or nominal 6 in.). Therefore, 9.5 mm (3/8 in.) plywood panels were used as spacers to accommodate the gap. The section views in Figs. 4 and 5 show all components including the spacers. In this figure, the timber rivets for the steel hanging connection are partially shown for illustration.

The engineering design followed the Canadian standard [1] and also referred to the APA guideline [2]. The APA guideline and its cited standards were only used where Canadian standards are mute or vague. This strategy was used to make sure that the final design was in compliance with Canadian regulations. The design checked bending resistance, web shear, flange-web shear, shear transfer through panel joints, deflection, stiffeners and lateral stability. In particular, the web-flange shear action was developed through the gluing surfaces by adhesive. The Canadian standard permits the use of scarf-joints in order to increase the shear transfer through panel joints. For the ease of construction, plywood panels used in this project were butt-jointed (Fig. 3). The deflection of the PWB was dominated by shear deflection, as the moment of inertia of the beam section is very large. Regular stiffeners were sufficient to distribute loads, except at the supports, where large reaction forces were to be developed through the stiffeners. At these locations, 130 × 266 (5-1/8 in. × 10-1/2 in.) D.Fir-L glulam members replaced the regular 38 × 140 (nominal 2 × 6) sawn lumber stiffeners, which can transfer heavy concentrated loads to the supporting beam via a timber rivet hanging connection (Fig. 3). Lateral stability was provided by roof joists for simple beams and diagonal braces for cantilever beams on the compression edge.

The integrity of the PWB relied on the gluing effect between flanges and panels. Nailing was used to apply a pressure needed to create positive contact to cure the adhesive. The APA guideline [2] states that the web-flange shear should not be transferred by any combination of glue with mechanical fasteners. Since the Canadian timber design standard [1] does not specify the requirement of nailing, the prescriptive requirements in the APA guideline were used in this project. The nails for the inner-layer plywood panels were 65 mm (2-1/2 in.) long, while the nails for the outer-layer plywood panels were 76 mm (3 in.) long. Typical nail spacing was 76 mm (3 in.) at panel edges along the stiffeners and 152 mm

Fig. 2. Overview of the construction (photo credit: Patkau Architects Inc.).

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