

Advancing Timber for the Future Built Environment

EXPERIMENTAL STUDY ON PULL-OUT STRENGTH OF TIMBER JOINTS INCORPORATING HIGH-DAMPING RUBBER ~EFFECTS OF EMBEDMENT LENGTH AND THICKNESS OF HIGH-DAMPING RUBBER~

Komei MORIMUNE¹, Hisamitsu KAJIKAWA², Chongbing YAN³

ABSTRACT: This study examined timber joints incorporating high-damping rubber, with the objective of achieving joints that possess high strength, rigidity, toughness and damping performance for use in medium- to high-rise and medium-to large-scale timber buildings. Pull-out tests were conducted on timber joints with varied embedment length, shape and thickness of high-damping rubber to elucidate the load-displacement relationships and failure modes. The effects of these parameters on pull-out strength were also clarified, with the goal of proposing a mechanical model that accounts for these factors. The experimental results contribute to the development of such a mechanical model.

KEYWORDS: Timber joints, High-damping rubber, Pull-out strength, Embedment legth, Thickness of high damping rubber

1 – INTRODUCTION

1.1 BACKGROUND

In medium- to high-rise and medium- to large-scale timber buildings, the joints connecting structural components must possess not only high strength and rigidity but also sufficient toughness to absorb seismic energy. Accordingly, the authors' laboratory undertook a study of timber joints incorporating high-damping rubber that possess high toughness and damping performance.

1.2 STUDY OBJECTIVES

The ultimate objective of this study is to propose a mechanical model for the joints that takes into consideration the effects of embedment length, shape and thickness of high-damping rubber.

In this paper, pull-out tests were conducted with varying parameters of the joint components to experimentally investigate the load-displacement relationship and failure modes. The effects of these parameters on pull-out strength were also examined.

2 – OVERVIEW OF TIMBER JOINTS IN-CORPORATING HIGH-DAMPING RUBBER

Figure 1 shows an overview of the timber joint incorporating high-damping rubber. The joint is composed of

a steel rod, high-damping rubber, a steel pipe, an adhesive layer, and glued laminated timber. It is fabricated by drilling a hole in the timber, filling it with adhesive, and inserting the rod. Incorporating high-damping rubber improves the joint's toughness by inducing shear failure in the rubber layer prior to shear failure in the adhesive layer or the timber.



Figure 1: Overview of the joint

¹Komei MORIMUNE, Meiji University, Graduate Student, ce243049@meiji.ac.jp

²Hisamitsu KAJIKAWA, Meiji University, Prof., Dr.Eng., kajihisa@meiji.ac.jp

³Chongbing YAN, Sumitomo Rubber Industries, Ltd., Dr.Eng., c-yan.az@srigroup.co.jp

3 – PULL-OUT TEST OF THE JOINTS WITH VARYING EMBEDMENT LENGTHS AND HIGH-DAMPING RUBBER SHAPES

3.1 EXPERIMENTAL OBJECTIVES

Figure2 shows the scene of the pull-out test. Pull-out tests were conducted using specimens with varying embedment lengths and high-damping rubber shapes to investigate their effects on pull-out strength and failure modes[1].



Figure 2: Scene of the pull-out test



Figure 3: Diagram of test specimens

3.2 OVERVIEW OF TEST SPECIMENS

Figure3 shows a diagram illustrating the cross-sectional geometry of the test specimens. The specimens were fabricated by drilling a 31 mm diameter hole into the end grain of glued laminated timber with a cross-section of 90 mm × 90 mm, inserting a joint consisting of a steel pipe, steel rod, and high-damping rubber, and bonding them with epoxy adhesive. The steel rod used was SCM435, the steel pipe was SS400, the adhesive was TE243-L2, and the laminated timber was Douglas fir conforming to the JAS standard E120-F375. The high-damping rubber used was isoprene-based.

Figure 4 shows the naming convention used for the test specimens. Each specimen name consists of the shape and diameter of the steel rod, the thickness of the high-damping rubber, the embedment length, the cross-sectional area of the timber, and the specimen number.

Table 1 lists the parameters of the test specimens. The test parameters included two steel rod shapes (straight and wavy) and three embedment lengths (140 mm, 200 mm, and 260 mm), resulting in a total of six specimen types. The wavy steel rods had a maximum diameter of 14 mm and a minimum diameter of 10 mm. The high-damping rubber used in these specimens had thicknesses ranging from 2 mm to 4 mm.

3.3 EXPERIMENTAL METHOD

Figure 5 shows the experimental setup. The loading system consisted of a 500 kN hydraulic jack mounted on a fixture attached to a base. The load was applied at a rate of 1 mm per 10 seconds until failure. A load cell and a displacement gauge were used to measure the load and displacement.

S - D14t2L140 - A090-1 Diameter of Rod Sectional area D14-14mm A090-90×90 Thickness of High-damping rubber t2-2mm Embedment length

L140→140mm, L200→200mm, L260→260mm Shape of Rod S→Straight, W→wayy

Figure 4: Test specimen name

	Table 1	: List	of test	specimens
--	---------	--------	---------	-----------

Name	Diame- ter of rod	Thickness of high-dmping rubber	Embedment length	Sectional area	
S-D14t2L140- A090-1 S-D14t2L140- A090-2 S-D14t2L140- A090-3	-		140		
S-D14t2L200- A090-1 S-D14t2L200- A090-2 S-D14t2L200- A090-3	14	2	200	90×90	
S-D14t2L260- A090-1 S-D14t2L260- A090-2	-		260		
W-D14t2L140- A090-1 W-D14t2L200-	10 ~ 14	2~4	140 200		
A090-1 W-D14t2L260- A090-1	10.014		260		



Figure 5: Experimental setup

3.4 LOAD-DISPLACEMENT RELATION-SHIPS AND FAILURE MODES

The load-displacement relationships for the S-type and W-type specimens are shown in Figure 6, the experimental results are summarized in Table 2, and the failure modes are illustrated in Figure 7. In all specimens, both a yield strength and a ultimate strength were observed. The yield point is defined as the point at which the displacement of the joint begins to change. For the straight-shape specimens, the yield point occurred at approximately one-fifth of the ultimate strength, and for the curved-shape specimens, it occurred at approximately one-third of the ultimate strength. As deformation progressed, the load continued to increase until the high-damping rubber sheared at a displacement of 12-15 mm, at which point the ultimate strength was reached. Additionally, when the high-damping rubber sheared, a splitting failure was observed in the laminated timber due to the internal force, which caused the timber to split outward.



Figure 6: Load-displacement relationships

Table 2: The test characteristic values

Name	Strength at yield point [kN]	Ultimate strength [kN]	Displacement at ultimate strength [mm]	
S-D14t2L140- A090-1	8.86	50.28	14.41	
S-D14t2L140- A090-2	8.69	44.78	15.35	
S-D14t2L140- A090-3	8.25	38.50	13.38	
S-D14t2L200- A090-1	12.41	67.28	13.15	
S-D14t2L200- A090-2	12.27	60.16	13.28	
S-D14t2L200- A090-3	11.50	63.97	13.65	
S-D14t2L260- A090-1	17.10	87.69	14.08	
S-D14t2L260- A090-2	16.60	85.44	13.20	
W-D14t2L140- A090-1	8.04	27.99	16.55	
W-D14t2L200- A090-1	11.01	37.65	13.42	
W-D14t2L260- A090-1	13.99	46.48	11.14	



Figure 7: Failure modes

4 – PULL-OUT TEST OF THE JOINTS WITH VARYING EMBEDMENT LENGTHS AND THE THICKNESS OF HIGH-DAMPING RUBBER

4.1 EXPERIMENTAL OBJECTIVES

Figure8 shows the scene of the pull-out test. Pull-out tests were conducted using specimens with varying embedment lengths and thicknesses of high-damping rubber to investigate their effects on pull-out strength and failure modes [3].



Figure 8: View of the pull-out test

4.2 OVERVIEW OF TEST SPECIMENS

Figure 9 shows a diagram of the test specimens. The cross-section area of the laminated timber was changed to $120 \text{ mm} \times 120 \text{ mm}$, while the other materials were the same as those used in Chapter 3.

Figure 10 shows the naming convention of the test specimens, which follows the same rules as in Chapter 3.

Table 3 lists the test specimens. The test parameters include four variations each of steel rod diameter and high-damping rubber thickness, and five embedment lengths (50 mm, 100 mm, 140 mm, 200 mm, and 260 mm), resulting in a total of 12 different specimen combinations.



Figure 9: Diagram of test specimens



Figure 10: Test specimen name

	Name	Diameter of rod	Thickness of high-dmping rubber	Embedment length	Sectional area
	S-D10t4L050-			50	
	A120-1				
	S-D10t4L100-			100	
	A120-1		4	100	
	S-D10t4L140-	10		140	
	A120-1				
	S-D10t4L200-	S-D10t4L200- A120-1 S-D10t4L260- A120-1		200	
	A120-1			200	
	S-D10t4L260-			260	
	A120-1			200	
	S-D12t3L140-	12	3	140	
	A120-1		5	110	
	S-D14t2L050-			50	120×120
	A120-1				120 120
	S-D14t2L100-		2	100	
	A120-1			100	
	S-D14t2L140- A120-1 14 S-D14t2L200-	14		140	
				200	
	A120-1	A120-1 D14t2L260- A120-1		200	
	S-D14t2L260-			260	
	A120-1				
	S-D16t1L140-	16	1	140	
	A120-1	-0			

Table 3: List of test specimens

4.3 EXPERIMENTAL METHOD

Figure 11 shows the experimental setup. The loading device used was the same as the one described in Chapter 3. In this experiment, the specimens were fixed with a fixture to prevent vertical movement. The load was applied at a rate of 1 mm per 10 seconds until failure.

Measurement instruments included a load cell and a displacement gauge. In this experiment, the ambient temperature at the start of each test was recorded for temperature correction purposes. All test results were then normalized to a reference temperature of 20°C.



Figure 11: Experimental setup

4.4 LOAD-DISPLACEMENT RELATION-SHIPS AND FAILURE MODES

Figure 12 shows the load – displacement relationships of the 12 test specimens. Yield strength and ultimate strength were observed in all specimens. The yield strength was approximately one-fifth to one-eighth of the ultimate strength. As deformation progressed, the load increased until shear failure occurred in the high-damping rubber, which defined the ultimate strength. Figure 13 shows the failure mode of specimen S-D14t2L050-DF120-1.



Figure 12: Load-displacement relationships



Figure 13: Failure modes

5 – PULL-OUT STRENGTH OF THE JOINTS

5.1 PULL-OUT STRENGTH-EMBEDMENT LENGTH RELATIONSHIPS

Figure 14 shows the relationship between pull-out strength and embedment length. Linear regression using the least squares method was performed for each shape and thickness of the high-damping rubber. Regardless of the shape or thickness of the high-damping rubber, the pullout strength at the yield point and the muximum strength increased in proportion to the embedment length. Furthermore, in specimens with 4 mm thick high-damping rubber, those with shorter embedment lengths tended to fall below the values predicted by the regression curves. This suggests that greater rubber thickness leads to a more uneven stress distribution, resulting in a decrease in maximum strength.



Figure 14: Pull-out strength-embedment length relationships

5.2 EFFECT OF HIGH-DAMPING RUBBER SHAPES ON PULL-OUT STRENGTH

Figure 15 shows the load-displacement relationships for each embedment length, comparing different shapes of high-damping rubber. For all embedment lengths, the ultimate strength of the S-type specimens was approximately twice that of the W-type specimens. This suggests that the strength is influenced by the shape and average thickness of the high-damping rubber, which may be attributed to stress concentration. The displacement at ultimate strength was approximately 15 mm. In the case of W-type specimens, the displacement at ultimate strength tended to decrease as the embedment length increased.

5.3 EFFECT OF HIGH-DAMPING RUBBER THICKNESS ON PULL-OUT STRENGTH

Figure 16 shows the load-displacement relationships for different high-damping rubber thicknesses at each embedment length. When the embedment length was the same, specimens with thinner high-damping rubber tended to exhibit higher pull-out strength and smaller displacement. A similar trend was observed in the shear test [2] of the high-damping rubber shown in Figure 16(f), where thinner rubber exhibited higher shear stiffness, which is considered to be the reason for this behavior. However, for specimens with a rubber thickness of 1 mm, the pull-out strength decreased. It remains unclear whether this reduction was due to mechanical factors or issues related to manufacturing.

6 – AVERAGE SHEAR STRESS-SHEAR STRAIN RELATIONSHIP

Figure 17 shows the relationship between shear stress and shear strain for each embedment length. In Figures 17(a) to 17(c), the average shear stress values were similar up to a shear strain of approximately 2. Beyond that point, the W-type tended to exhibit higher shear stress than the S-type. The maximum shear stress of the S-type was about twice that of the W-type, and the corresponding shear strain was also greater for the S-type. Additionally, as the embedment length increased, the shear strain at the point of maximum shear stress in the W-type decreased. In Figures 17(d) to 17(h), the shear stress values remained similar up to a shear strain of around 4. After that, specimens with thicker rubber or shorter embedment lengths tended to reach maximum shear stress earlier, with both the shear stress and shear strain at failure decreasing accordingly.



Figure 16: Comparison of load-displacement relationships by thickness of high-damping rubber



Figure 17: Average shear stress-shear strain relationships for each embedment length

7 – SUMMARY

This study verified the following findings.

- Based on the results of the pull-out tests, both the yield point—where the high-damping rubber begins to deform—and the maximum strength—where the rubber fails—were observed in all specimens. The maximum strength of the S-type specimens was approximately twice that of the W-type, which is considered to be due to differences in stress distribution resulting from the rubber shape. Additionally, it was observed that as the rubber thickness increased, the amount of deformation also increased, indicating that ductility performance can be controlled by adjusting the thickness.
- It was found that the pull-out strength of the joints is proportional to the embedment length, regardless of the shape or thickness of the high-damping rubber. In specimens with a rubber thickness of 4 mm, those with shorter embedment lengths exhibited lower maximum pull-out strength, which is considered to result from stress concentration. Furthermore, when the embedment length was the same, specimens with thinner high-damping rubber tended to exhibit higher pull-out strength.
- For all specimens, the shear stress values were similar up to a certain strain; however, beyond that point, the values began to differ, with thinner specimens exhibiting higher maximum shear stress. As the embedment

length increased, the maximum shear stress tended to converge to similar values regardless of thickness. These findings suggest that the shape, thickness, and embedment length of the high-damping rubber influence the stress distribution. A future task is to clarify the stress distribution through finite element analysis.

8 – CITATIONS

REFERENCES

- H. KAJIKAWA and C. YAN. Experimental study on extraction strength of wooden structural joints incorporating high damping rubber. Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan.Structures III. 2023.
- [2] H. KAJIKAWA, M. TAKAOKA, H. OGAWA, and Y. Igarashi. A study on mechanical properties of highdamping rubber dampers PART1 to 2. Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan.Structures III. 2023.
- [3] K. MORIMUNE, H. KAJIKAWA, and C. YAN. Experimental study on extraction strength of wooden structural joints incorporating high damping rubber PART2:Influence of embedment length and thickness of high damping rubber. Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan.