Direct Shear Transfer Mechanism Between Concrete And Glued Laminated Timber

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SUMMARY:

The authors have planned to transfer the shear force using shear key formed by concrete and timber as a direct shear transfer mechanism. To verify whether the mechanism would be effective or not, the authors performed direct shear experiments. The specimens were made using normal strength concrete and Japanese cypress laminated timber, which had no reinforcing bars in the concrete of the shear keys.

The ratio of the length (h) to the thickness (t) of the shear key was selected as a parameter of the specimens. The experimental results are reported in this paper, from those results the authors derived the following conclusions;

1. The shear force could be transferred by the expected shear transfer mechanism.
2. Different failure modes were observed in the specimens by varying the ratio of h/t.

Keywords: Hybrid Structure, Concrete, Glued Laminated Timber, Shear force, Shear Key

1. INTRODUCTION

1.1 Background of hybrid structure using timber and concrete

It is well-known that wood has light weight and good strength and ductility for bending force, so timber member is suitable for beam and girder. Also wood has good strength and ductility for compressive force; timber member is suitable for column. But in case of fire, fire damage of timber columns will cause collapse of building, so some architects and building engineer thinks that columns should be made by non-combustible materials, such as concrete. And when timber column located outer face of buildings get covered with water and soil, those will cause erosion of timber columns. Especially, hot spring water or gas from hot spring causes quick erosion of timber columns. So it is useful for prevention of erosion of columns to use concrete for columns.

So it will be said that hybrid structure, formed by concrete and wood, or steel and wood, will perform good structural characteristics based on each materials' mechanical characteristics.

Taking into mechanical characteristics of wood and concrete into consideration, the authors have planned hybrid structure formed by reinforced concrete(R/C) columns and glued laminated timber(W) beams(R/C-W hybrid structure) for using structural frame of low and middle rise buildings.

To connect W beams to R/C columns, metal fittings, such as screw bolts, dowels and steel bars, will be used in joints. Because tensile force caused by bending moment can be transferred only metal fittings set between W beams and R/C columns. Joint research about such mechanism had performed on the Ministry of Land, Infrastructure, Transport and Tourism, Japan in 2002.

But to transfer shear force between W beams and R/C columns, not only metal fittings but also direct touch mechanism, such as shear keys, are effective. If all bending moment and shear force should be transferred by metal fittings, number of metal fittings will increase. That will cause narrowness of interval between each metal fitting, and split failure of W beam will be caused.

If only tensile force can be transferred by metal fittings and shear force can be transferred by direct touch mechanism, number of metal fittings will decrease.

In this paper, the authors performed experimental study for direct shear transfer mechanism formed by R/C and W shear keys on R/C-W hybrid structure's joint. The authors has tried to make clear whether such shear keys can transfer shear force or not, and to make clear mechanical and ultimate failure properties of such shear key.

1.2. Detail of joint between R/C beam and W beam

Detail of joint which the authors have devised is shown in Figure 1. On shear key part of specimens, part of concrete has been projected, and part of timber has been dented. On specimens connecting bars has not been arranged because the authors would like to know only mechanical property of shear key in this research.

2. OUTLINES OF EXPERIMENTS

2.1 Specimens

2.1.1. Detail of specimens

Detail of specimens is shown in Fig.2, and list of specimens is shown in Table 1. Shape of shear key, shown in Fig. 3, was trapezoid having 45 degree-slant oblique sides. Shear key of all specimens has 30*mm* same tall (*t*=30*mm*, fixed value). But bottom length of shear key (*h*) has varied from 90*mm* to 210*mm* in each specimen. So ratio of "*h/t*" has varied from 3 to 7. Reason of 30*mm* tall of shear key is that aggregate which has 25*mm* diameter will completely fill into shear key if shear key has 30mm tall. Depth of shear key was 180*mm* which was as same as depth of specimens.
In specimens part of R/C had approximately 400*mm* width, 700*mm* tall and 180*mm* depth. Two parts of W were attached to the part of R/C from both sides; part of W had 200*mm* width, 700*mm* tall and 180*mm* depth.
Any connecting bars were not arranged across joint part between part of R/C and part of W. And when form of specimens was removed, the authors separated part of R/C from part of W by using hardware.

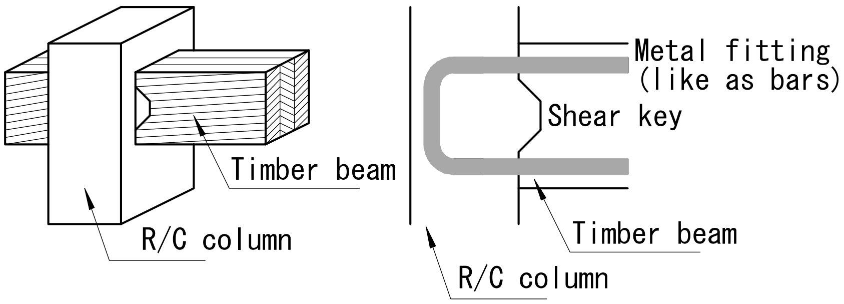


Figure 1. Detail of R/C-W hybrid structure's joint which the authors have devised

Table 1. List of specimens

Spec. name	Age of concrete (*days*)	Shear key's information					
		Bottom length h(*mm*)	Tall t(*mm*)	h/t	Bottom section area $A_{sc}(mm^2)$	Slant angle θ (deg.)	Number of shear keys
h90t30	61	90	30	3	16200	45	1 for right and 1 for left
h120t30	46	120		4	21600		
h150t30	61	150		5	27000		
h180t30	66	180		6	32400		
h210t30	66	210		7	37800		
h0t0	46	No shear keys					

$A_{sc} = h \times 180mm$ (180mm is width of part of W)

$L_{wb} = 0.5 \times (600 - h)$ (mm)

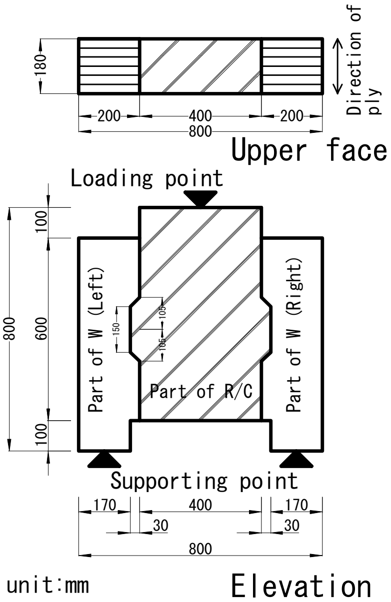


Figure 2. Detail of specimens;
For example the spec. *h210t30*

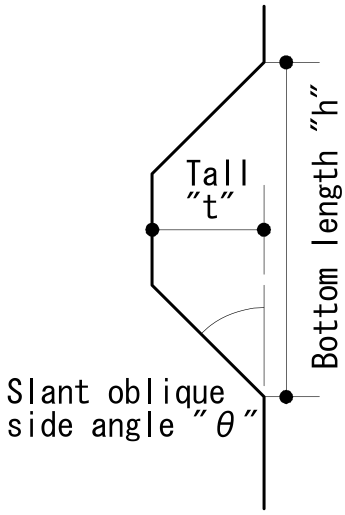


Figure 3. Detail of shear key

So the authors regard that shear force is transferred between part of R/C and part of W only by following two mechanisms; direct transfer mechanism caused by interlock of shear keys and frictional mechanism on interface between concrete and timber. But in this study the authors did not measure frictional coefficient on interface between concrete and timber, so shear force transferred by frictional mechanism cannot be measured.

In part of R/C reinforcing deformed bars which had 10mm of diameter were arranged, but those bars did not arrange near and on joint.

2.1.2. Mechanical properties of materials for specimens

Mechanical properties of concrete and glued laminated timber are shown in Table 2 and Table 3. Compressive strength of concrete became about 40N/mm^2. Glued laminated timber for this research's specimens was made of 6-ply Japanese cypress; 1 ply had 30mm of thickness. That glued laminated timber was ranked in Japan agricultural Standard as "E105-F300"; which means that the Young's modulus of the timber becomes near 10.5×$10^3 N/mm^2$, and bending strength becomes 30.0N/mm^2.

It is well-known that mechanical anisotropy of wood is very strong, so it should be mentioned that compressive strength and the Young's modulus shown in Table 3 is effective on situation that compressive force's direction correspond with timber's fibre direction.

And it should be also mentioned that, in this research, direction of shear force which shear key suffered corresponded with direction of fibre of timber.

Table 2. Mechanical properties of concrete for specimens

Spec. name	*h120t30* *h0t0*	*h90t30* *h150t30*	*h180t30* *h210t30*
Comp. strength σ_B (N/mm^2)	41.6	43.5	44.2
Young's modulus Ec (×$10^4 N/mm^2$)	2.9	2.9	2.9
Tensile Strength σ_t (N/mm^2)	2.6	2.7	2.8

Table 3. Mechanical properties of glued laminated timber

Comp. strength σ_{wc} (N/mm^2)	Young's modulus E_{wc} (×$10^4 N/mm^2$)	Water content
47.2	2.16	11.0% ~ 13.5%

2.1.3. Way of making of specimens

The way of making of specimens is shown in Photo 1., and mentioned as follows;

1. Form of specimens were made; and part of W of specimens were set in the form.
2. Reinforcing deformed bars were arranged in part of R/C.
3. Fresh concrete were filled into the forms. So when filling concrete, fresh concrete and part of W touched each other.
4. Concrete was cured in more than 7 days. After curing, form was removed. At that time the authors separated part of R/C from part of W.
5. Separated specimens were assembled again. After assembling, 20mm diameter's bolts were arranged around assembled specimens in order not to separate. Bolts were tied very lightly.
6. After tying, specimen was set in loading apparatus, and loading experiment was performed.

2.2 Loading to specimens

Loading apparatus is shown in Photo 2. Monotonous compressive load was suffered to top of specimen by universal testing machine. While loading, light tying of bolts arranged around specimen had been kept, so the authors think that joint interface did not suffer any rectangular compressive force acting from outer part.

Slip displacement between pat of R/C and part of W was measured, but separate displacement between both parts was not measured by reason by arranging of bolts.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Loading results

3.1.1 Relation between Q and δ

Loading results are shown in Fig. 4 and Table 4, and example of ultimate failure patterns of specimens are shown in Photo 3. In this research, the authors have thought that loading force will be provided half to each, right and left, shear key as shear force, so shear force "Q" written later is defined as a half of loading force to specimens by loading apparatus.

Fig.4 shows relation between shear force "Q" and slip displacement between part of R/C and part of W "δ".

From "Q_{max}" which is the maximum loading force, more than 200kN of shear force could be transferred between part of R/C and part of W by shear key.

3.1.2 Ultimate failure pattern of specimens

From ultimate failure patterns of specimens, it will be said that shape of shear key related to ultimate

Photo 1. Way of making specimens;
Filling concrete into form for specimens

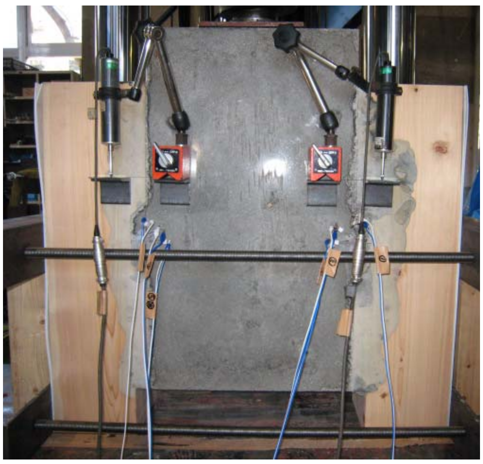


Photo 2. Loading apparatus;
Specimen set to the apparatus

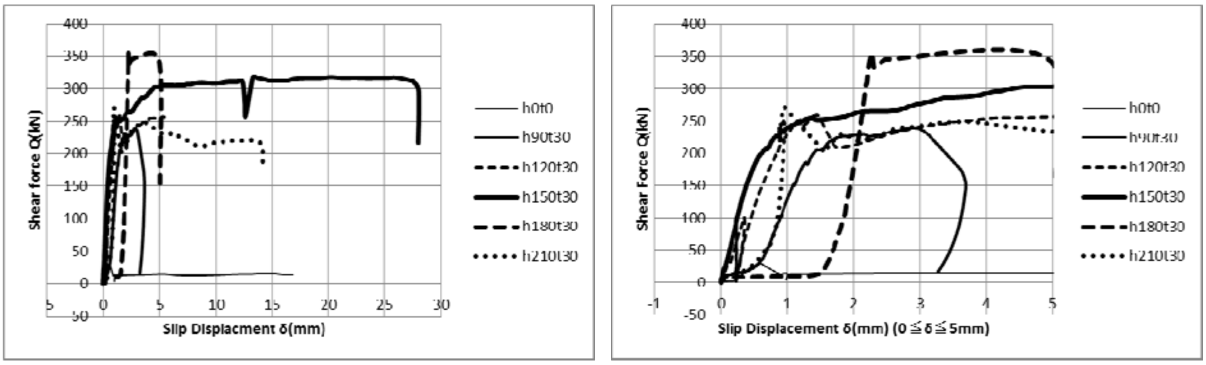


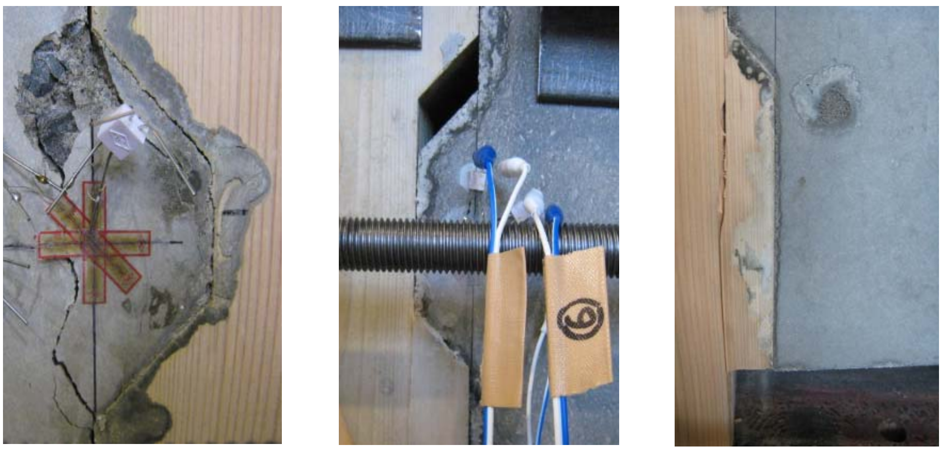
Fig 4. Relations between shear force "*Q*" and slip displacement " *δ*

Table 4. Loading results

Spec. name	Maximum loading Force Q_{max} *(kN)*	δ_{max} *(mm)*			Ultimate failure pattern	
		Right joint	Left joint	Average	Right joint	Left joint
h90t30	238.8	2.14	3.61	2.87	*CS*	*CS*
h120t30	259.4	1.41	1.46	1.43	*CS*	*CS*
h150t30	317.8	13.37	13.26	13.31	*WC*	*WC+CC*
h180t30	354.5	N/A	2.28	2.28	*WS*	*WS*
h210t30	271.1	1.43	0.49	0.96	*WS*	*WS*
h0t0	29.0	0.19	1.02	0.60	*SP*	*SP*

"*Q*" is a half value of loading force.
δ_{max}: Slip disp. between part of R/C and part of W when loading force reached to Q_{max}
Ultimate failure pattern:
CS: Concrete shear cut-off failure on bottom face of shear key
CC: Compressive failure of concrete on side face of shear key
WC: Compressive failure of timber on side face of shear key
WS: Shear cut-off failure of timber on outer area of shear key
SP: Part of R/C and part of W separated each other.

failure pattern. For example, on ultimate failure pattern of the spec. *h90t30* and *h120t30*, those ratios of "*h/t*" is smaller than 4, concrete on bottom face of shear key was failure in shear cut-off, instead that any part of W had no damage. On those two specimens, loading force became larger with only



Spec. *h90t30* Shear key on right part | Spec. *h150t30* Shear key on left part | Spec. h210t30 Shear key on left part

Photo 3. Example of ultimate failure patterns of shear key little slip displacement between part of R/C and part of W before loading force reached to maximum. When loading force reached to maximum, sudden shear cut-off failure on bottom of shear key occurred with large sounds, and after that loading force decreased suddenly.

On the other hand, on the spec. *h150t3*, that ratios of "*h/t*" is equal to 5, ultimate failure patter of right shear key differed from that of left shear key. Concrete part of right shear key was not destroyed and side face of wood was destroyed. When slip displacement was little, shear force became large. But slip displacement became large, shear force did not become not large. After maximum shear force, sudden decrease of shear force did not occur. Failure of shear key occurred after slip displacement became 12mm.

On specimens h180t30 and h210t30, those ratio of "*h/t*" were larger than 6, shear key was not destroyed. But shear cut-off failure of timber on outer area of shear key was occurred. Relation between shear force and slip displacement had large initial stiffness, and became maximum shear force situation. After maximum shear force, shear cut-off failure of timber on outer area of shear key was occurred with large sound seemed to cut of wood.

In condition that glued laminated timber was made of Japanese cypress which has near $10.5\times10^3 N/mm^2$ of the Young's modulus and near $30.0 N/mm^2$ of bending strength, and concrete which has $40 N/mm^2$ of compressive strength, following facts made clear from experimental results;

1. When ration of "h/t" become smaller than 4, concrete on bottom face of shear key will fail in shear cut-off.
2. When ration of "h/t" is equal to 5, side face of shear key will fail in compression.
3. When ration of "h/t" is larger than 6, shear cut-off failure of timber on outer area of shear key will occur.

3.2 Evaluation of maximum shear force

In this section, the authors try to estimate maximum shear force of specimens by using materials' mechanical properties and shape of specimens.

3.2.1 For specimens h90t30 and h120t30

Both specimens failed in shear cut-off of concrete on bottom face of shear key. So maximum shear force will be estimated by using shear strength of concrete. It is well-known that shear strength of concrete has strong relation to its compressive strength. So in this paper, the authors assume that shear strength of concrete is equal to one-tenth times of its compressive strength, and that maximum shear strength of specimens will be estimated by way of multiplication of "Area of bottom of shear key A_{skb} shown in Table 5" by shear strength of concrete.

Comparison between maximum shear force of specimens and estimate value are shown in Table 5. Maximum shear force became larger than estimate value. So it will be said that estimate value will lead safety results.

3.2.2 For specimen h150t30

On specimen *h150t30*, it will be said that compressive strength of timber will strongly have influence on maximum shear strength. So the authors assumed that maximum shear strength of specimen h150t30 will be estimated by way of multiplication of "Area of side of shear key A_{sks} shown in Table 6" by compressive strength of timber.

Comparison between maximum shear force of specimen and estimate value is shown in Table 6. Estimate value became larger than maximum shear force. So it will be said that estimate value will lead dangerous results. One of reasons why estimate value became large will be that compressive strength of timber will become small. That situation will be caused by direct touch between timber and fresh concrete. In that situation, water in fresh concrete will transfer to timber. It is well-known that

Table 5. Comparison between maximum shear force and estimate value on Spec. *h90t30* and *h120t30*

Spec. Name	$0.5Q_{max}(kN)$	$\sigma_B(N/mm^2)$	Area of bottom face of shear key $A_{skb}(mm^2)$	$Q_{cal1}= 0.1\cdot\sigma_B\cdot A_{skb}(kN)$	$0.5Q_{max}/Q_{cal1}$
h90t30	119.4	43.5	16200	70.5	1.69
h120t30	129.7	41.6	21600	89.9	1.44

$A_{skb}=h\times180mm$

Table 6. Comparison between maximum shear force and estimate value on Spec. *h150t30*

Spec. Name	$0.5Q_{max}(kN)$	$\sigma_{wc}(N/mm^2)$	Area of side face of shear key $A_{sks}(mm^2)$	$Q_{cal2}=\sigma_{wc}\cdot A_{sks}$(kN)	$0.5Q_{max}/Q_{cal2}$
h150t30	158.9	47.2	5400	254.9	0.62

$A_{sks}=（t=30mm）\times 180mm$

Table 7. Comparison between maximum shear force and estimate value on Spec. *h180t30* and *h210t30*

Spec. Name	$0.5Q_{max}(kN)$	$\sigma_{ws}(N/mm^2)$	Outer area of shear key		$Q_{cal3}=\sigma_{ws}\cdot A_{wb}(kN)$	$0.5Q_{max}/Q_{cal3}$
			Length $L_{wb}(mm)$	Area $A_{wb}(mm^2)$		
h180t30	177.3	9.0	240	43200	386.9	0.46
h210t30	135.6	9.0	225	40500	362.7	0.37

$\sigma_{ws}=0.19\cdot\sigma_{wc}$ $A_{wb}=L_{wb}\times 180mm$ L_{wb}: Shown in Table 1.

high water content causes weakness of timber.

3.2.3 For specimens h180t30 and h210t30

On specimens *h180t30* and *h210t30*, shear cut-off failure of timber on outer area of shear key was occurred. So it will be said that shear strength of timber will strongly have influence on maximum shear strength. The authors did not measure shear strength of timber , because it is difficult to get shear strength of timber by experiment. But it is well-known that shear strength of timber has influenced by compressive strength of timber. So in this research the authors assumed that shear strength of timber is 19% as same as compressive strength of timber, and also assumed that maximum shear strength of both specimens will be estimated by way of multiplication of " Area on outer part of shear key A_{wb} shown in Table 7" by shear strength of timber and any coefficient.

Comparison between maximum shear force of specimens and estimate value is shown in Table 7. Estimate value became larger than maximum shear force. So it will be said that estimate value will lead dangerous results. One of reasons why estimate value became large will be, also as specimen *h150t30*, that compressive strength of timber will become small.

4. CONCLUSION

In this research following facts have made clear by loading experiments;

1. Shear key formed by concrete and glued laminated timber can transfer shear force directly.
2. Ultimate failure pattern of shear key under shear key was influenced by shape of shear key, especially by ratio "*h/t*" defined by between bottom lengths "*h*" ant height "*t*". If ration of "*h/t*" became smaller than 4, concrete on bottom face of shear key failed in shear cut-off. If ration of "*h/t*" was equal to 5, side face of shear key failed in compression. And if ration of "*h/t*" was larger than 6, shear cut-off failure of timber on outer area of shear key occurred.

AKCNOWLEDGEMENT

This study was supported by WASS Research Centre at Toyo University. And the authors would like to say great thanks to Prof. S. Nagasawa, Prof. K. Kudo, Toyo Univ., and Prof. M. Inoue, Oita Univ., Japan.

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