Timber Guardrail Combined of Round Log Rails and Concrete Posts

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Summary
This research program was initiated to develop a timber guardrail combined of round logs to withstand the force of vehicle impact. To meet both of the requirements of crashworthy and low occupant risk of a severe vehicle impact, a series of full-scale crash tests have been completed in this program in order to find the proper geometric form of round logs and the earth-embedded posts, and the hardware to connect the round log rails to supporting posts. The timber guardrail successfully developed in this program consists of two round logs, which are fixed to the reinforced concrete posts. This structure form is easy for the exchange of round logs when they lose the serviceability due to the decay in the future.

Keywords: timber guardrail, log rail, vehicle crash test, acceleration, concrete post

1. Introduction
Guardrail, as the most popular crash safety barriers, has been made of steel rails and steel posts historically on the basis of full-scale vehicle crash testing evaluation. On the other hand, round logs have been utilized as effective safety barriers from the ancient age. To increase the use of timber materials in infrastructure has an active ecological effect on natural environment protection [1]. A timber guardrail of steel-backed lumber, approved by the Federal Lands Highway Office, was developed in the United States as aesthetic barriers installed in scenic areas. A French private firm has developed a lograil system of composite steel channel and timber for both the vertical and horizontal components by taking the advantages of impact absorbing quality of the timber and high tensile resistance of the steel. In these two types of timber barrier, railing system was designed as a timber-steel composite to withstand the impact force of vehicle and to redirect the vehicle.

Maintenance of the barrier devices of combined two kinds of materials with different decay processes during the service periods would be some intricate. Considering the advantage of impact absorbing quality of wooden material, round logs has been recognized as one kind of appropriate element of railing system of longitudinal barriers. It is possible to develop a railing system by using
raw timber alone.

This project was started from 1994, the object at that stage was to extend the usage of the vast amount of fallen trees of Sugi in Kyusyu hit by a severe typhoon. In 1998, the standard for road safety barrier recommended by Japan Road Association was revised. By the old standard, road crash barriers for the protection of vehicles should be made from metal or concrete, whereas at the revised standard, instead of the specification of the materials used in barriers, evaluation procedures of the performance of road crash barrier were specified in details. The revised standard opens the door for the use of wood materials in road crash barriers.

Usually, guardrails made of metal materials, is classified as flexible barriers, that have low occupant risk than the rigid barriers, such as concrete barriers. For type B guardrail or Type C guardrails, the criteria of occupant ridedown acceleration limits in the longitudinal and lateral direction are less than 90 m/s² in each consecutive 10-ms period. The most difficult problem in this project encountered was that round log with small diameter could not have enough strength to contain the impacting vehicle and round log with a large diameter would lead to an occupant ride down acceleration larger than the limit. Relative position of the two rails also had great influence on occupant ride down acceleration. In this project, a series of full-scale crash tests had been conducted from 1999 in order to find the proper geometric form of round logs and the earth-embedded posts, and the hardware to connect the round log rails to supporting posts.

2. Structural Design by Static Test

2.1 Basic Design

Basic form of the timber guardrail was designed as shown in Fig. 1. Two log rails are fixed by reinforced concrete post at a span of 2 meters. From the recommended design procedure for the railing systems of bridge, the ultimate bending moment of upper log rail or lower log rail needed for type C guardrail with a span of 2 meters was estimated as around 17kN·m. Static bending test of 80 pieces of Sugi specimens with a diameter of 180mm or 200mm was carried out in order to find the distribution of bending strength of Sugi. Table 1 shows the test results. It was found that log rail of Sugi with a diameter of 180mm could meet the requirement of 17kN·m. There were two reasons to set the span as 2 meters. The first was that a longer span would require the log rail in a larger diameter over than 200mm to meet the strength requirement, which was not easy to handle in the installation site. The second was that the barrier should be easy to install at the curved part of local road in Japan.

![Fig. 1 Elevation of timber guardrail](image)

<table>
<thead>
<tr>
<th>Table 1 Distribution of ultimate bending strength of Sugi</th>
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<tbody>
<tr>
<td>Average (N/mm²)</td>
</tr>
<tr>
<td>Standard deviation (N/mm²)</td>
</tr>
<tr>
<td>Minimum (N/mm²)</td>
</tr>
<tr>
<td>Maximum (N/mm²)</td>
</tr>
<tr>
<td>Number of samples</td>
</tr>
<tr>
<td>CV(%)</td>
</tr>
</tbody>
</table>

When the vehicle impact to the flexible guardrail made of steel, the guardrail can deform a great deal to contain and redirect the vehicle. Because the deformation capacity of timber material is not so high comparing with steel material, timber guardrail can not produce a large deformation as steel guardrail during the vehicle crash. The post for timber guardrail must have a larger supporting strength and rigidity than that of the post for steel guardrail. In this project, reinforced concrete post was chosen with large rigidity than steel post. The log rails were fixed to the post by bolted connection. Usually, concrete post can keep the serviceability about 50 years or longer, whereas log rails will decay at an expected life of 10 years. When the log rails lose their serviceability, it is easy to exchange the log rails.
2.2 Static Test

Test results on the bending strength of Sugi log rails have been illustrated in Table 1 (Fig. 2). The average ultimate bending strength of 80 Sugi log rails was 44.7 N/mm², and the standard deviation was 4.83 N/mm². It was supposed that both of the upper log rail and lower log rail should have an ultimate bending capacity of 17kN·m. For the log rail in a diameter of 180mm, the necessary ultimate bending strength was as follows:

\[
\sigma_u = \frac{M}{W} = \frac{17\text{kN} \cdot \text{m} \times 1000000}{\pi \cdot 180^3/32} = 29.6 \text{N/mm}^2
\]

From the bending test results in Table 1, log rails of 180mm diameter had a sufficient strength as the railing system of timber guardrail. Although the dispersion in strength of timber material could be larger than that of metal, there was sufficient strength guarantee to use log rail of Sugi in a diameter of 180mm to constitute the timber guardrail of Type C.

The supporting capacity of post was measured by applying a horizontal force at the central post of four-span guardrail in right angle to the axis of the guardrail (Fig. 3). Three kinds of posts: concrete, steel pipe and H shape steel, were installed. Relationship between deflection and load of three kinds of posts is illustrated in Fig. 4. The accumulated area between the curve of deflection-load and deflection reflects the structural capacity of the guardrail to withstand the impact of vehicle and to absorb the crash energy and contain, redirect the vehicle. It can be found that the accumulated area of reinforced concrete post was the largest of the three kinds of post.

The timber log rail was connected to concrete post by bolting the two ends of the log rail to the post. The connection strength was tested by applying a horizontal force to the log rail in the direction of the guardrail. It was found that the designed connection method kept its function until the post inclined nearly to the ground.

3. Full Scale Vehicle Crash Tests

Although computer simulations can provide an evaluation of guardrail at a good extent, the vehicle impact process is so complicated that modelling all the factors of timber guardrail in this project theoretically still has some difficulties. Full-scale vehicle crash testing is the most common method to evaluate the performance of newly designed guardrail. During the development of the timber guardrail in this project, full scale vehicle crash test had been conducted more than thirty times. Test requirements and evaluation criteria followed the current standard for road safety barrier recommended by Japan Road Association [2, 3].

3.1 Test Requirements and Evaluation Criteria

The current Japanese standard for road safety barrier has two test levels of Test A and Test B. The vehicle type, vehicle mass, impact speed, and impact angle relative to the guardrail axis are specified according to the installing type of the guardrail. Table 2 lists the general outlines of impact vehicle requirements and evaluation criteria for type B and type C guardrails (flexible barriers). Except the vehicle impact requirements, the date acquisition, embedment condition, and construction of the testing guardrail are also specified.
Table 2 Impact vehicle requirements and evaluation criteria

<table>
<thead>
<tr>
<th>Impact vehicle requirements</th>
<th>Evaluation criteria</th>
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<tbody>
<tr>
<td><strong>Level</strong></td>
<td><strong>Embedment condition</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Mass</strong></td>
</tr>
<tr>
<td>Test A (truck)</td>
<td>25.0 ton⁴</td>
</tr>
<tr>
<td>Test B (passenger car)</td>
<td>1.0 ton</td>
</tr>
</tbody>
</table>

|                            | C         | 26         | >45kJ       | Vehicle intrusion⁵ | <1.1m           | Vehicle intrusion⁵ | <0.3m       |
|                            |           |            |             |                   |                 |                 |

1 Calculating equation for impact energy (IE) \( \text{IE} = \frac{1}{2} \cdot m \cdot (V^2 / 3.6 \cdot \sin \theta) \)

2 Measured by distance of the inside plane of front wheel intruded into the barrier from original position of barrier plane

3 Calculated by a moving 10-ms average of vehicular “instantaneous” accelerations measured at a period of 0.5 msec.

4 Due to the limit of propulsion instrument, truck with a mass of 20.0 ton can be used instead of 25.0 ton truck, but the impact speed should be increased to meet the requirement of impact energy.

3.2 Test Methodology

Most of the full-scale crash tests of timber guardrail were conducted at the Shirahama outdoor temporary test field located in Hyuga city, Miyazaki Prefecture and the final appraisal tests were conducted at the NILIM collision test course. The mass of vehicle, impact speed, impact angle, exit speed, exit angle were measured mechanically or by analyses of the high-speed motion photography taking from a height of 20 meters direct to the above of the impact point (Fig. 5). Ridedown accelerations of X and Y direction of the impacting passenger car were recorded by accelerators mounted at the centre of mass of the vehicle (Fig. 6). In order to assess the vehicle impact force acting on the timber log rails and concrete post, in some of the tests, strain of the log rails and concrete posts were measured.

3.3 Test Results and Discussions

Fig. 7 shows the Crash sequence of test level A for 20.0 ton truck at a speed of 35 km/h, impacting the timber guardrail at an angle of 15.9° to longitudinal guardrail axis. Fig. 8 shows the condition of guardrail and truck after the test. Fig. 9 shows the Crash sequence of test level B for 1.0 ton passenger car at the impact condition shown in Table 2. Fig. 10 shows the condition of guardrail and car after the test. Timber guardrail had enough capacity to withstand the impact of vehicle and to absorb the impact energy.

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Fig. 5 Testing site

Fig. 6 Accelerators mounted on car

Fig. 7 Crash sequence for 20.0 ton truck at a speed of 35 km/h, impacting the timber guardrail at an angle of 15° to longitudinal guardrail axis
Because the impacting force of passenger car to timber guardrail concentrated on the lower log rail, the height of the log rails, especially the height of lower log rail had a great influence on vehicle acceleration. To evaluate the influence of the position of log rails on acceleration and look for the properly height of lower rail with a relative lower occupant risk during the crash event, a series of passenger car crash tests were conducted to measure the acceleration at different height of lower log rail. The height of upper log rail was fixed at 650mm, and the height of lower log rail was chosen as 410mm, 380mm, 360mm, 330mm, 300mm and 220mm. The embedment soil layer for all the tests was kept the same with an N-value of around 20~30.

Fig. 11 illustrates the vehicle acceleration wave when the height of lower log rail was 410 mm. The highest moving 10-ms average acceleration value at X direction was 121.6 m/s²/10ms, excess the limit of 90 m/s²/10ms. The front wheel impacted with the lower log rail and then had a direct collision with the post (Fig. 12).
Fig. 13 and Fig. 14 illustrate the vehicle acceleration waves as the height of lower log rail was 360mm and 300mm, respectively. The highest moving 10-ms average acceleration value at X direction in Fig. 13 and Fig. 14 was 83.4 m/s²/10ms and 67.7 m/s²/10ms, respectively. Comparing the vehicle acceleration wave at different height of lower log rail, it was found that the moving 10-ms average acceleration value at the height of log rail of 300mm was the lowest result.

For type B timber guardrail, a comparing test to confirm the influence of the rigidity of lower log rail on acceleration was conducted. The diameter of upper log rail was fixed as 200mm and the diameter of lower log rail was chosen as 180mm and 200mm. The highest moving 10-ms acceleration at X direction was 79.8 m/s²/10ms and 110.9 m/s²/10ms, respectively. The moment of inertial of 200mm log rail was about 1.5 times to that of 180mm log rail, the acceleration increased with the moment of inertial. The diameter of lower log rail should not exceed 180mm with the structural form of timber guardrail developed in this programme.

In addition to above tests, crash tests to determine the strength of hardware utilized to connect the log rail to post were also conducted. From the test results, the hardware easily to connect the neighbouring log rails to share the impact force was developed.

4. Conclusions

In this project, Type B and Type C timber guardrail using Sugi log rail were successfully developed.

1) There was sufficient strength guarantee to use log rail of Sugi in a diameter of 180mm to constitute the timber guardrail of Type C

2) The timber guardrail developed had enough structural capacity to withstand the impact of vehicle and to absorb the impact energy and contain, redirect the vehicle.

3) The height of lower log rail with a relative lower occupant risk during the crash event was chosen as 300mm.

4) The diameter of lower log rail should not exceed 180mm with the structural form of timber guardrail developed in this programme.

5. References

