FRICTION-BASED SLIDING BETWEEN STEEL AND STEEL, STEEL AND CONCRETE, AND WOOD AND STONE

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ABSTRACT :

This paper presents a series of shaking table studies on the friction coefficients between steel and mortar, steel and steel, and wood and stone. The sliding behavior suggests that the characteristics of the materials, such as the hardness and roughness, affect the friction coefficients during sliding motion. For the steel to steel tests, the local material damage changes the contact condition. Plowing of the two surfaces along with heat generated during sliding provided a wide range of friction coefficients. For the steel to mortar tests, the mortar is damaged locally as a result of scraping during the initial sliding, but soon the behavior becomes stable. The friction coefficient is about 0.5 initially and raised to a stable value of about 0.8. Tests of wood columns sitting on a stone base plate exhibit stable friction coefficient of about 0.5, with almost no damage on the base plane.

KEYWORDS: Friction coefficient, steel and concrete, steel and steel, wood and stone

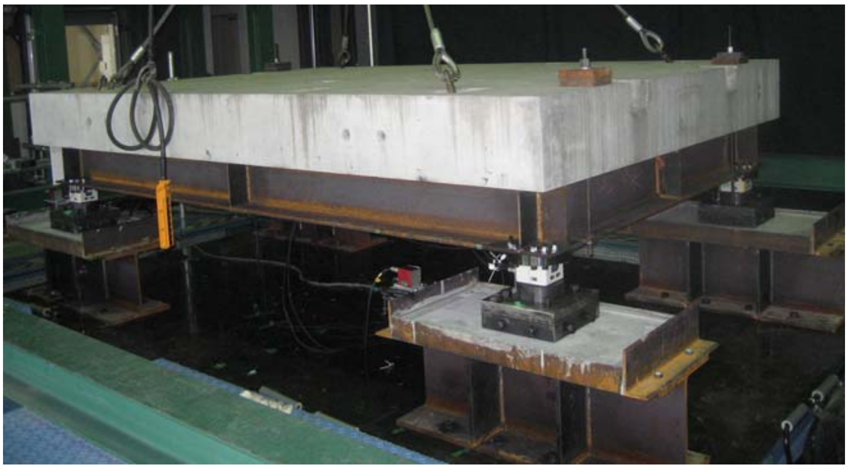
1. INTRODUCTION

Friction is a form of resistance in connecting elements and members. Applications of friction devices also increase recently particularly in combination with base-isolation and passive damping systems. For base-isolation, friction with low friction coefficients is preferred, all the while in passive damping systems friction with medium to high friction coefficients are often adopted. Although much research has been done in the examination into the friction coefficients for materials used in base-isolation and passive damping systems, the friction characteristics of conventional materials, say, steel versus steel, steel versus concrete, or wood versus stone, have not been explored extensively except for few (Nagae et al 2005). In particular, information on sliding and dynamic friction of such combinations of materials is very limited.

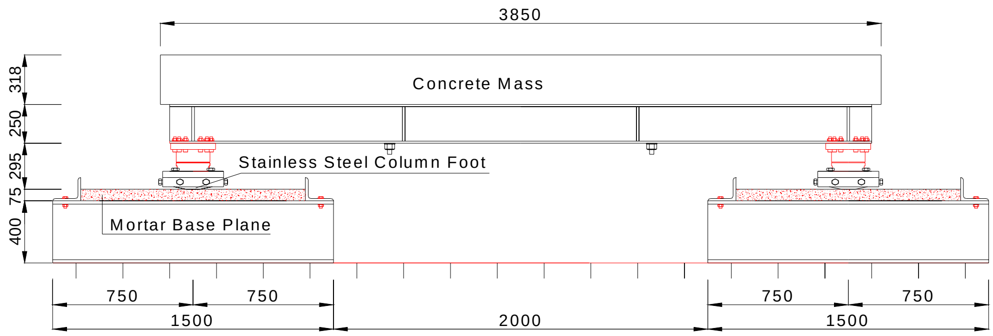
These combinations, however, do exist in real applications. In old wood houses such as temples, main wood columns are often placed directly on top of the foundation stone without any physical connection between the wood column and foundation stone. In steel building structures, steel column bases are often supported by concrete and mortar underneath the column base. They are normally connected by anchor bolts, but friction between the steel place and the underneath concrete or mortar is often counted for the horizontal resistance. Metal touch is common in building contents made of steel that are placed on top of steel plank. This paper examines the dynamic friction characteristics, including the friction coefficients corresponding to the initiation of sliding and the changes of the coefficients by repeated sliding. The study is experimental, and shaking table tests are conducted to obtain the necessary information.

2. SHAKING TABLE TEST FOR FRICITON BEHAVIOR OF STEEL AND MORTAR

A large-scale shake table study was conducted to determine the fundamental sliding characteristics between steel and mortar and steel and steel under dynamic loads. The six degree of freedom shake table (3 m by 5 m) owned by the Disaster Prevention Research Institute of Kyoto University, Japan, was used. The shake table can provide a maximum acceleration and velocity of 1.0 g and 1.5 m/s in each direction. All shaking was performed in the direction parallel to the long dimension of the shake table. The test specimen used to evaluate the sliding behavior consisted of three main elements: the lower friction surface (either mortar or steel), the upper friction surface (steel), and the rigid mass as shown in Figure 1. The test specimen had four points of contact.



(a)



(b)

Figure 1 Test specimen used to evaluate the sliding behavior

2.1 Test for Combination of Steel and Mortar

In the tests for the combination of mortar and steel, the mortar surfaces were cast on top of Japanese steel H-Sections (similar to U.S. I-sections) and secured to the H-sections using steel studs. Steel angles attached to the H-section were used to border the mortar surface to provide a stable and immobile block. The H-sections were the only portion of the test specimen which was directly bolted to the shake table. The dimensions of the mortar surface were 550 mm by 1020 mm allowing for approximately 300 mm of sliding in either direction when the steel surface is placed at the center of the mortar surface. Material tests showed that the mortar had compression strength of 35 N/mm^2 at the time of testing.

The steel friction elements adopted as the upper friction surface consisted of 250 mm by 250 mm by 60 mm blocks of steel which were tapered on one side down to a 75mm by 75 mm square. This smaller square had a polished surface and represented the contact area with the lower friction surface. The steel friction element was held in place under the load cells and connected to the rigid mass. Vertical and horizontal bolts allowed for adjustment of the slope of the steel friction surface to ensure full contact with the mortar and equal distribution of the gravity load between each of the four points of contact.

The rigid mass consisted of a 68.6 kN concrete block sitting on top of a 9.2 kN horizontal steel frame. The concrete mass was connected to the steel frame using PC bars at four points. Combining the weight of the concrete block, steel frame, load cells, and steel friction blocks provided a total specimen weight of 82.0 kN. This overall weight results in a pressure of 14.6 N/mm^2 on the mortar surface at the contact points. Further details and dimensions of the test specimen can be seen in Fig. 1(b). The test specimen was instrumented with tri-axial load cells to measure both the vertical load at each contact point and the shear force generated by the contact between the steel and mortar. Laser displacement transducers were used to measure the absolute displacements of both the mortar surface and rigid frame while strain potentiometers were used to directly measure the relative sliding between the two. Accelerometers were also installed on the concrete mass and on the surface of the shake table in order to obtain both relative and absolute acceleration values.

Sliding occurred from the inertial acceleration rose to 0.5g, and the concrete base plane surfaces were damaged locally by repeated mortar scraped off, as shown in Fig 2. The steel column scrapes into the mortar surface with even obtuse edges, as shown Fig. 3. These changed the contact condition. Accordingly, the friction coefficient, defined as the horizontal shear force divided by the weight, changed, from about 0.5 initially to about 0.8 afteward. It is notable, however, that the coefficient becomes rather stable after a few cycles and for further repeated cycles, the coefficient value remained relative unchanged. Figure 4 shows an example of the friction coefficient time history.

Fig 2 Scraped mortar plane surface

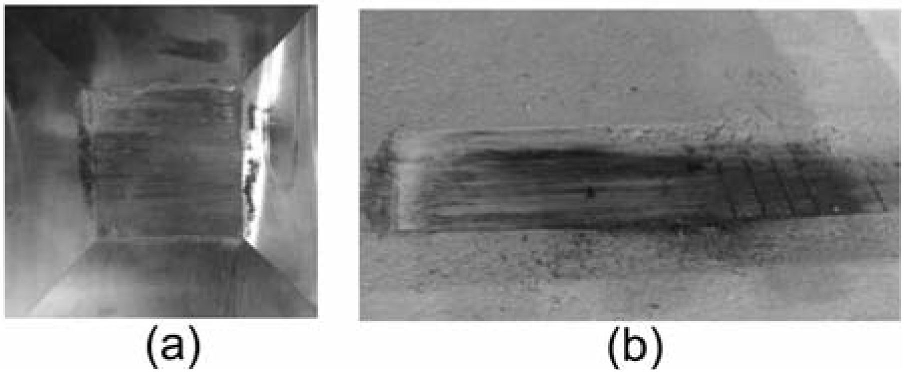


Fig 3 Scraped steel plane surface

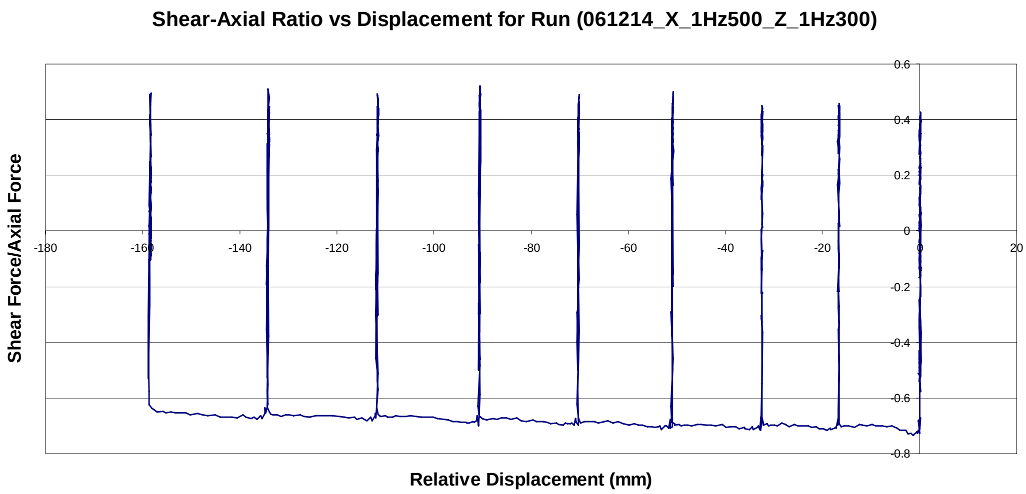
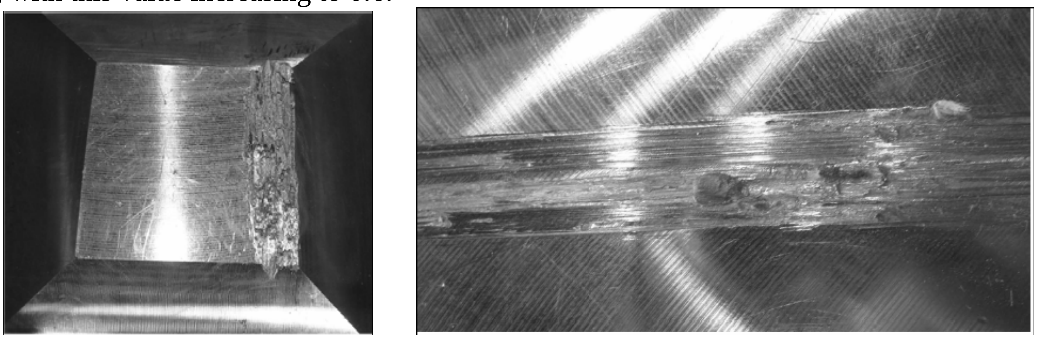


Fig 4 Change in friction coefficient with repeated sliding

2.2 Test for Combination of Steel and Steel

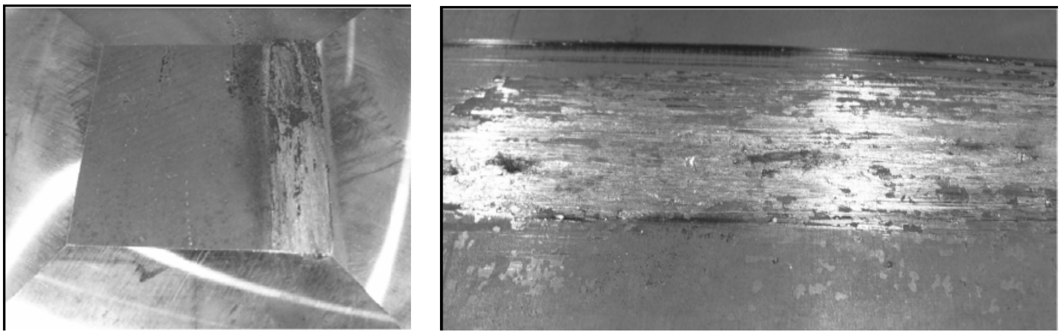
Two rounds of shaking table test were conducted to determine the sliding characteristics between steel and steel under dynamic loads. The test setup was the same as that used for the tests for the combination of steel and mortar. In the first round, the steel surfaces were polished intestinally. A steel place instead of mortar was placed for the lower friction surface. Sliding occurred from the inertial acceleration rose to 0.15g, but the polished steel base plane surfaces also were damaged locally even more severely by repeated adhesion and prow or wedge formation. Double-sided adhesive wear occurred easily, at interface built-up edge rose the friction coefficient higher and higher, shown in Fig 5. For example, the initial static friction coefficient was 0.15, with this value increasing to 0.6.



(a) (b)

Fig 5 The adhesion and prow or wedge formation on friction surface between polished steel plates

The second round of test was conducted for the combination steel and steel with the black-skin left as it was. Until the black skin was removed locally by reciprocated friction sliding, the coefficient was relatively stable and constant. The thin and stiff black skin was soon penetrated through, and afterward, almost the same phenomena observed as in the polished steel specimen replayed (Fig. 6). On the damaged base plate surface, some adhesion bonding points looked like flamed scar, which showed that the frictional heat was concomitant.



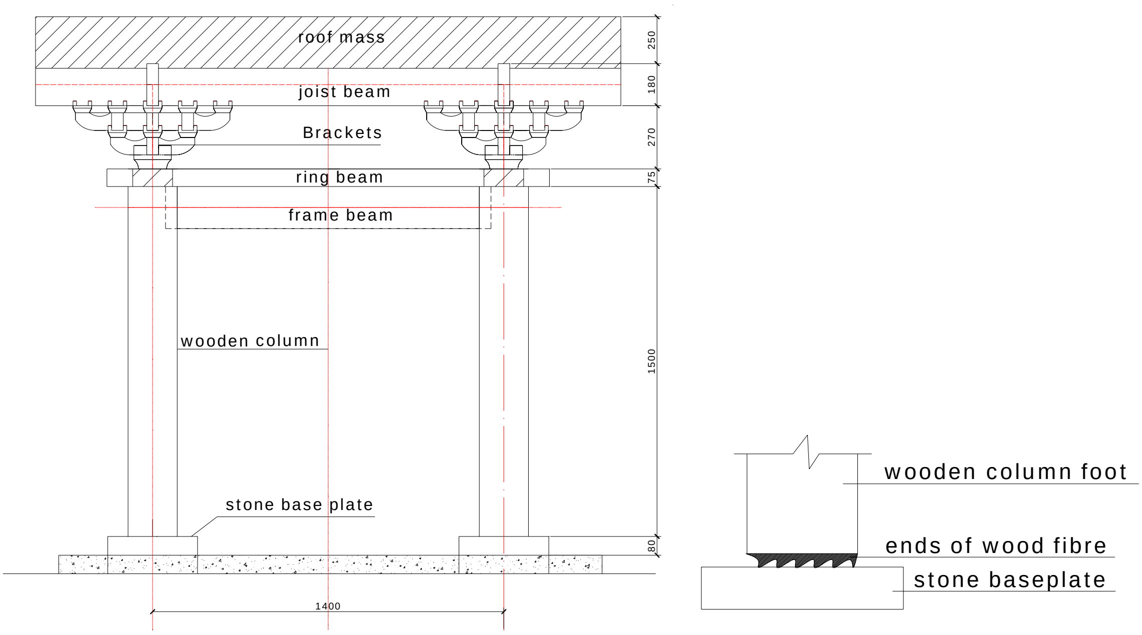
（**a**） （**b**）

Fig 6 Adhesion on friction surface between steel plates left with black-skin

3. SHAKING TABLE TEST FOR FRICITON BEHAVIOR OF WOOD AND STONE

Another shaking table study was conducted to determine the fundamental characteristics of a Chinese palace timber frame structure. The columns of the frame were placed on the stone block without tight connection (Fig. 7). The specimen was an exact replica designed and constructed based on "YIN ZAO FA SHI", then the national civil engineering code of the Song dynasty of 1011. Following the code, smooth and stiff stone blocks were used as the base plates. The shake table used in the test is owned by the Xi'an University of Architecture & Technology, China, with a plan dimension of 2 m by 2.2 m. The shake table can provide a maximum acceleration and velocity of 1.0g and 1.0 m/s in the horizontal direction. The test specimen used to evaluate the sliding behavior consisted of three main elements: the stone base plate surface, the wooden column bottom surface, and the frame as can be seen in Fig. 7(a). The test specimen had four points of contact where sliding occurred to roughly simulate four column bases in a building structure.

(a)



(b)

Fig 7 Shake table test specimen of Chinese timber frame

The scale ratio of specimen was adopted to be 1/3.52, to follow a precise scale with which each member could be made easily using the code. The roof mass consisted of a 36 kN concrete block sitting on top of a 4 kN timber frame. The diameter of the each column was 210 mm, the total weight 40 kN of the superstructure made about 0.29 N/mm^2 average compressive stress at the column bottom. The specimen frame had a natural frequency of 2.44 Hz. The static friction coefficient between the wood column and stone plate was observed to be 0.4 to 0.5 from a previous test. Further details and dimensions of the test specimen are shown in Fig. 7(b) and reported in Zhang et al (2002).

The specimen was excited by sinusoidal waves having a frequency close to the natural frequency of the specimen. The excitation rose from zero to a value of about 4 m/s^2 in the acceleration amplitude, when the structure sustained significant drifts, and continued for 200 s. The friction behavior between wood and stone was very stable. The tail-end of wood fibers at the bottom of the columns apparently acted as cushions, and this flexible material neither dig nor plowed into the stiff stone. The damage to the stone was nearly none, too.

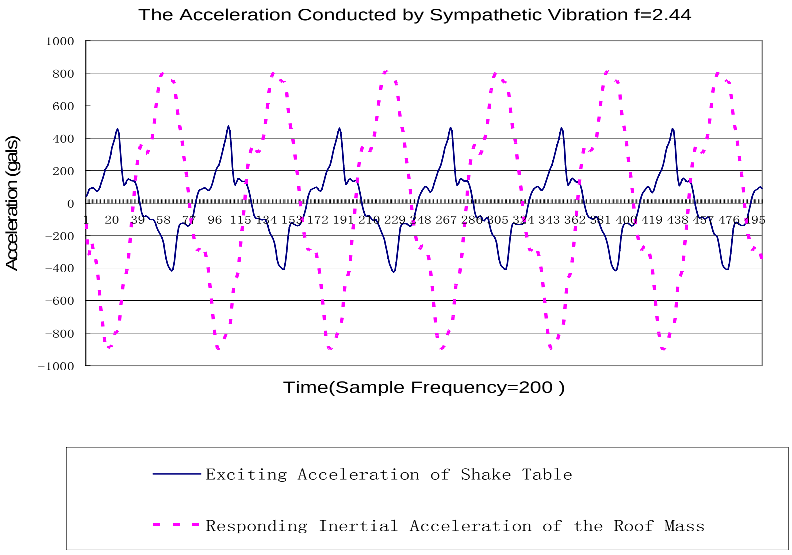


Fig 8 Response of timber frame subjected to sinusoidal input motion

(a) **(b)**

Fig 9 Displaced wood column without damage to stone base

4. CONCLUSION

Dynamic friction behavior for the combination of conventional materials, i.e., steel versus mortar, steel versus steel, and wood versus stone, was examined by multiple shaking table tests. For the combination of steel and mortar, the friction coefficient increased in the initial stage of repeated cycles (from about 0.5 to 0.8), but soon (after few cycles) it became stable and remained relatively unchanged for many more succeeding cycles. The initial increase was attributed to the damage to the mortar induced by the counterpart steel. For the combination of steel and steel, the friction coefficient continued to rise from a small value of about 0.15 to nearly 0.6 primarily due to the severe local damage caused by repeated adhesion and prow or wedge formation. The friction coefficient was most stable for the combination of wood and stone, maintaining a constant value of 0.5 for many repeated cycles.

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