

Consideration of the Power in Karate-doh from the Viewpoint of Impact Engineering

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ABSTRACT

Karate-doh is known as a traditional Japanese Budoh (martial arts). The present study is concerned with the verification of the power generated in Karate-doh. The impact forces produced by the hand techniques in Karate-doh were examined by means of Tameshi-wari for concrete beams. Tameshi-wari by Shutoh-uchi (sword hand) was performed for simply supported concrete beams, and the impact response and the breaking of concrete beams were examined. In order to understand the mechanism of impact breaking of concrete beams by Karate-doh hand techniques, numerical simulations were also carried out using a dynamic finite element method with a Newmark- β method. As a result, it was found that the reaction at both ends of the beam was almost never generated by virtue of the dominant modes of impact bending deformation of the beam. This suggests that the impact breaking of concrete beams floating in air is quite within the bounds of possibility by means of Tameshi-wari. Therefore, Tameshi-wari for concrete beams suspended in air was also tried, and then the predicted result was achieved.

Keywords: Impact force, Impact strength, Stress waves, Concrete beam, Impact breaking, *Karate-doh*, *Tameshi-wari*.

INTRODUCTION

Karate-doh is known as a traditional Japanese *Budoh* (martial arts) with its origin from the islands of Ryukyu (Okinawa). In the original form of *Karate-doh*, some advanced techniques utilize also weapons such as *Boh* (staffs), *Nunchaku*, *Sai*, and so on. Nowadays, as a general rule, this art of self-defense is known as a *Budoh* that makes use of no weapons; only empty hands and bare feet are employed, Funakoshi (1964a, 1975b)

We are interested in what is the power generated by the techniques of *Karate-doh*, Daimaruya et al., (1994a, 1995b, 1995c, 1998d). The purpose of this study is to examine what kind of physical or mechanical quantities, for example, impact force, momentum (impulse) and kinetic energy, are dominant in the power

of empty hand techniques of *Karate-doh*. In this study, the impact force caused by *Karate-doh* techniques was estimated experimentally and theoretically. The impact force produced by the hand techniques of *Karate-doh*, such as *Shutoh-uchi* (sword hand) and *Tettsui-uchi* (hammer fist) are investigated by means of *Tameshi-wari* for concrete beams and numerical simulations. *Tameshi-wari* means the fracturing of rock, brick, wood and so forth by *Karate-doh* techniques and it is a kind of demonstration of the power that can be generated in *Karate-doh*.

In the experiment of *Tameshi-wari*, simply supported concrete beams (thickness 5 cm, width 10 cm and length 50 cm) were used. In order to understand the mechanism of the impact breaking of concrete beams, numerical simulations were carried out based on a dynamic finite element method with a Newmark- β method, Washizu (1981), Daimaruya et al., (1994).

It was found that, in simply supported concrete beams subjected to the impact force produced by the hand techniques of *Karate-doh*, the third mode of impact bending deformation of the beam is dominant, and then the reaction at both ends of the concrete beam was almost never generated. This suggests that the impact breaking of concrete beams floating in the air is quite within the bounds of possibility by means of *Tameshi-wari*. Therefore, *Tameshi-wari* for the concrete beam suspended in air was also tried, and then the predicted result was achieved. The corresponding numerical simulation was also carried out and the impact force generated by *Shyutoh-uchi* was estimated.

MECHANICAL PROPERTIES OF CONCRETE

Tameshi-wari was performed using concrete beams. The configuration of the concrete beam is rectangular with a thickness of $h = 5$ cm, a width of $w = 10$ cm and a length of $l = 50$ cm. Firstly the mechanical properties of concrete specimens were examined by several kinds of static and impact tests.

The concrete mix proportion used for this study is shown in Table 1. An ordinary Portland cement with fine and coarse aggregates was employed for the fabrication of concrete specimens. The maximum coarse aggregate size was chosen as 10 mm, considering the dimensions of the concrete specimens.

Static tests of direct tension, splitting tension, 3-point bending and compression were made. All static tests were conducted by using an INSTRON (model 5586) testing machine at the crosshead speeds of 0.05-0.5 mm/min. Table 2 shows the static mechanical properties of the concrete specimens obtained by the static tests. Each the strength is the mean value of cumulative fracture probability, which will be presented next. In Table 2, c_0 is the velocity of elastic waves, given by $c_0^2 = E/\rho$, which almost correspond to the experimental observation of the propagation of elastic waves through concrete specimens. Here E is the elastic modulus and ρ is the mass density. The impact tensile test was also performed by means of the method of reflected tensile stress waves, Daimaruya et al., (1997a, 1997b, 2000c, 2004d).

Statistical analyses may be required to treat the dispersion of the experimental data in relation to the concrete strengths. A Weibull distribution was applied to

not only the impact tensile strength but also the static strengths of the concrete specimen. To plot the i -th ranked sample from a total of n number of fractured specimens, a median-rank position was adopted, which is the distribution function F_i expressed approximately in terms of $F_i = (i-0.3)/(n+0.4)$. The data plotted on the Weibull probability paper, i.e., $\ln\{\ln[1/(1-F_i)]\}$ versus $\ln(\sigma)$ were laid on straight lines, as shown in Figure 1. The straight lines are drawn by means of the method of least squares. The Weibull modulus (shape parameter) m of each plot and the scale parameter ξ (fracture probability 63.2%) can be found from the Weibull distribution. The mean stress μ and the standard deviation $s.d.$ can be calculated based on such data. The statistical results of the concrete used for this study are shown in Table 3. Comparing the impact tensile strength with the static tensile strengths, it is worth noting that the impact tensile strength of the concrete is significantly influenced and increased by the loading rate conditions. Judging from this result, the impact bending strength is supposed to increase comparing to the static one due to strain rate of concretes. However, so far there is not any method of accurately measuring the impact bending strength, so that in this study the impact force generated by *Tameshi-wari* will be lowly estimated using the static bending strength which may be the least bending strength of the concrete beam.

Table 1. Mix proportion of concrete by weight.

Water	1.0
Portland cement	1.54
Fine aggregate	4.7
Coarse aggregate	2.24

Table 2. Mechanical properties of concrete.

Elastic modulus (E)	17 GPa
Mass density (ρ)	2.3×10^3 kg/m ³
Direct tension strength (σ_t)	1.7 MPa
Splitting tension strength (σ_{ts})	1.9 MPa
Bending strength (σ_b)	3.9 MPa
Compressive strength (σ_c)	22.5 MPa
Impact tensile strength (σ_i)	3.7 MPa
Velocity of elastic waves (c_0)	2.7×10^3 m/s

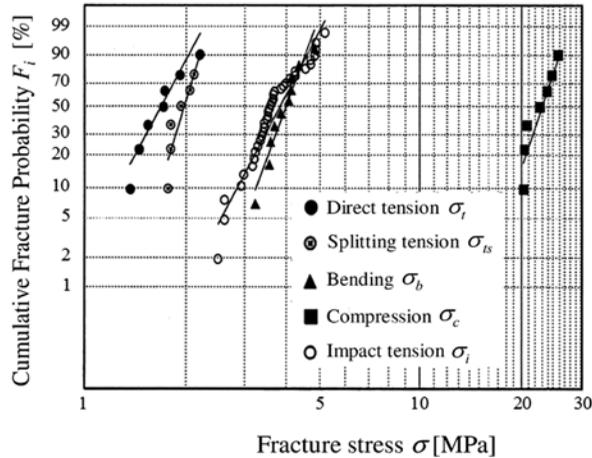


Figure 1. Weibull plots of concrete strengths.

Table 3. Results of statistical analysis.

Test	(σ_t)	(σ_{ts})	(σ_b)	(σ_c)	(σ_i)
Number of samples n	7	7	10	7	36
Shape parameter \square	6.25	11.4	9.27	10.7	6.32
Scale parameter ξ	1.82	2.04	4.14	23.5	3.99
Mean μ	1.7	1.96	3.94	22.5	3.72
Standard deviation $s.d.$	0.32	0.21	0.26	2.1	0.69

TAMESHI-WARI FOR A SIMPLY SUPPORTED CONCRETE BEAM

Tameshi-wari by means of *Shytoh-uchi*

Tameshi-wari was performed using concrete beams with the mechanical properties described in the former chapter 2. As has been mentioned, *Tameshi-wari* means the fracturing of rock, brick, wood and so forth by *Karate-doh* techniques and it is a kind of demonstration of the power that can be generated by the hands and feet techniques in *Karate-doh*.

We performed *Tameshi-wari* for simply supported concrete beams by the hand techniques in *Karate-doh*, such as *Shytoh-uchi* (sword hand) and *Tettsui-uchi* (hammer fist). Figure 2 shows the successive photographs of *Shytoh-uchi* for a concrete beam simply supported by concrete blocks at both ends.

In actuality, my sword hand comes down with *Kiai*. It is a shout but not just a voice. It is related to the way of breathing, however, the true nature of *Kiai* in *Karate-doh* has not been made clear scientifically yet.

Figure 3 shows the strain responses measured at the bottom of a concrete beam subjected to impact force by *Shytoh-uchi*. The strain gage 1 and 2 are glued on the center ($l/2$) and ($l/4$) of the span of the concrete beam, respectively. The breaking initiation of the concrete beam may be seen to begin at the time of

700~800 μsec after the impact of *Shyutoh-uchi*. However, the accurate estimation of the impact force generated between the hand and the concrete beam is difficult not only experimentally but also theoretically, because that, in impact bending of beams, the applying force is not correspond to the strain unlike in the case of static bending. This reason is that the bending deformation modes of beams subjected to impact loadings consist of complicated ones and vary with time. Moreover, the mechanical constitutive equation of our hands in *Karate-doh* techniques is unknown so that the impact force generated between the hand and the concrete beam will not be directly obtainable. In this study, the impact force acting on the concrete beam due to *Shyutoh-uchi* was obtained by a kind of inverse analysis using the mechanical properties of the concrete.

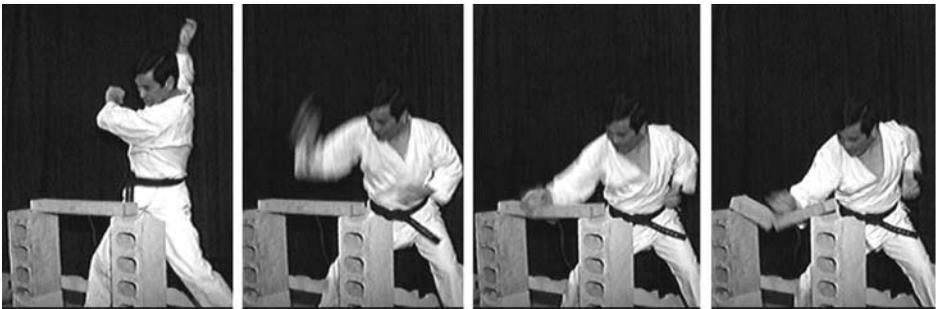


Figure 2. *Tameshi-wari* by means of *Shyutoh-uchi* for a simply supported concrete beam.

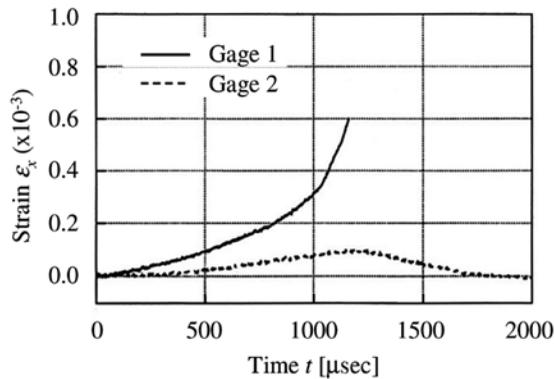


Figure 3. Impact strain responses at the bottom of a concrete beam impacted by *Shyuto-uchi*.

Numerical Simulation of Impact Response of Concrete Beam

In order to understand the mechanism of the impact breaking of concrete beams by means of *Karate-doh* techniques, numerical simulations were carried out based on a dynamic finite element method using a Newmark- β algorithm, Washizu (1981), Daimaruya et al., (1994).

The equation of motion for the finite element formulation is given by

$$[K]\{\Delta u\} + [M]\{\Delta \ddot{u}\} = \{\Delta F\} \quad (1)$$

where $[M]$ is the mass matrix, $[K]$ is the stiffness matrix. $\{\Delta u\}$ and $\{\Delta \ddot{u}\}$ denote the increment vectors of nodal displacements and nodal displacement accelerations, respectively, which are due to the increment vector of external forces $\{\Delta F\}$. The superposed dot denotes differentiation with respect to time.

The time integration of Eq. (1) is carried out by a Newmark- β algorithm in which the displacement u_n and the velocity \dot{u}_n are given as follows:

$$u_n = u_{n-1} + \Delta t \cdot \dot{u}_{n-1} + \left(\frac{1}{2} - \beta\right) \Delta t^2 \cdot \ddot{u}_{n-1} + \beta \Delta t^2 \cdot \ddot{u}_n \quad (2)$$

$$\dot{u}_n = \dot{u}_{n-1} + (1 - \gamma) \Delta t \cdot \ddot{u}_{n-1} + \gamma \Delta t \cdot \ddot{u}_n$$

By rewriting Eq. (2) in increment form, the following equations are obtained,

$$\{\Delta \ddot{u}\} = \frac{\gamma \{\Delta u\}}{\beta \Delta t} - \frac{\gamma \{\dot{u}_{n-1}\}}{\beta} + \left(1 - \frac{\gamma}{2\beta}\right) \Delta t \{\ddot{u}_{n-1}\} \quad (3)$$

$$\{\Delta \ddot{u}\} = \frac{\{\Delta u\}}{\beta \Delta t^2} - \frac{\{\dot{u}_{n-1}\}}{\beta \Delta t} - \frac{\{\ddot{u}_{n-1}\}}{2\beta}$$

Here, $\{\Delta u\} = \{u_n\} - \{u_{n-1}\}$, $\{\Delta \dot{u}\} = \{\dot{u}_n\} - \{\dot{u}_{n-1}\}$, $\{\Delta \ddot{u}\} = \{\ddot{u}_n\} - \{\ddot{u}_{n-1}\}$

The subscript n denotes the n -th time interval, and the parameters β and γ control the stability and accuracy of the algorithm, respectively.

By making use of Eq.(2) and (3), Eq.(1) may be written in the form

$$\left([K] + \frac{1}{\beta \Delta t^2} [M]\right) \{\Delta u\} = \{\Delta F\} + [M] \left(\frac{\{\ddot{u}_{n-1}\}}{2\beta} + \frac{\{\dot{u}_{n-1}\}}{\beta \Delta t}\right) \quad (4)$$

In order to insure stability of the solutions, the computations are carried out with $\beta = 1/4$, $\gamma = 1/2$, and the increment of the time Δt less than l_n/c_1 that corresponds to the time for the longitudinal wave with the velocity of c_1 in elastic body to be propagated the minimum node distance l_n . The simply supported concrete beam at both the ends is assumed to be in plane-strain state. The impact force is represented as a distributed force with 2 cm width acting on the center of the front surface of the concrete beam.

Figure 4 shows the numerical simulation model divided into four-node isoparametric elements for a simply supported concrete beam subjected to the impact due to *Shyutoh-uchi*. It is assumed that the impact force is given as a ramp-type force F with respect to time, which is based on the previous investigations. Here, the dimensionless time is defined as $T = c_1 t / 2h$, where t is time. The thickness of a concrete beam $h = 50$ mm and the velocity of the

dilatational elastic waves $c_1 = 2.7 \times 10^3$ m/s. Then, for example, at $T = 1.0$, the elastic wavefront generated at the center of the impact location is propagated approximately once back and forth in the thickness direction. F_0 and T_1 denote the impact breaking force and the dimensionless breaking time, respectively.

Figure 5 shows the dimensionless stress distributions *in the x and y directions in the concrete beam at the dimensionless time $T = 10, 15$ and 20* . Here σ_0 is the impact stress defined by $\sigma_0 = F_0/A_0$, where A_0 is the impacted area. The dimensionless time $T = 20$ corresponds to about $770 \mu\text{sec}$ in real time. From the figures, it can be seen that the third bending deformation mode of the concrete beam is dominant and the reactions at both ends of the beam are almost never generated. This is caused by the propagation of stress waves and their reflection and interference. They reinforce each other and produce the tensile stress concentration only near the center region of the bottom surface. The numerical results may suggest that the breaking of the concrete beam floating in the air is quite within the bounds of possibility.

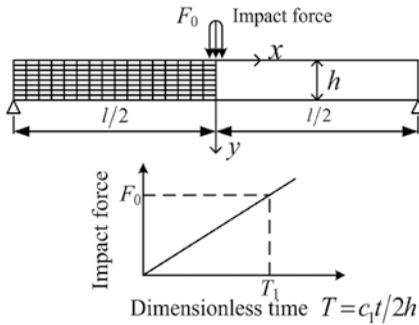


Figure 4. Model for numerical simulation.

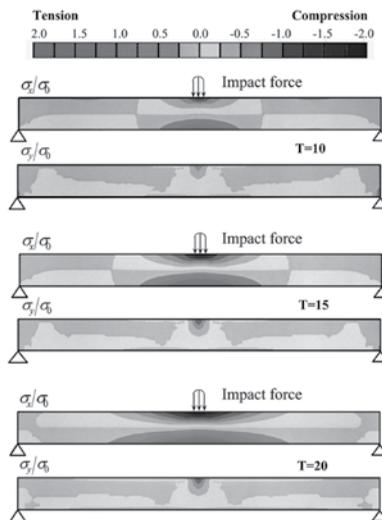


Figure 5. Dimensionless stress distributions σ_x / σ_0 and σ_y / σ_0 at dimensionless time of $T = 10, 15$ and 20 .

TAMESHI-WARI FOR A CONCRETE BEAM SUSPENDED IN THE AIR

Consequently, *Tameshi-wari* for concrete beams suspended in the air was also tried. We succeeded to obtain the result as predicted by the numerical simulation.

Figure 6 shows the successive photographs of *Tameshi-wari* for a concrete beam suspended in the air by means of *Shyutoh-uchi* in horizontal direction. He is striking his *Shyutoh* (sword hand) against the concrete beam with *Kiai*. The picture was taken by using a high-speed video camera operating at 4500 frames per second.

Figure 7 shows the strain responses measured in two trials at the bottom center of a concrete beam suspended in the air. Both the signals indicate that the breaking of the concrete beam starts at 700~ 800 μsec after the impact due to *Shyutoh-uchi*. Based on these strain responses, the numerical simulation of *Tameshi-wari* for a concrete beam suspended in the air was also carried out.

Figure 8 shows the dimensionless stress in a concrete beam at each dimensionless time. It can be seen that the deformation of the concrete beam is asymptotically transited from the third bending mode to the first bending mode of a beam.

The successive behavior of impact bending deflection of the concrete beam is shown in Figure 9. The deflections are exaggerated by about 600 times as large as real deflection. It can be seen that both the ends of the concrete beam move toward the opposite side to the direction of the impact force due to *Shyutoh-uchi*.

Figure 10 shows the numerical simulation for the variation of dimensionless stress with time at the bottom center of the concrete beam suspended in the air. The ordinate denotes the stress ratio σ_x/σ_0 . Here σ_0 is the unknown impact stress acting on the contact area between the hand and the concrete beam. The concrete beam may be broken when σ_x exceeds the braking strength of the concrete beam. The contact area was observed to be about $A_0=0.002 \text{ m}^2$ from another contact experiment between *Shyutoh* and the concrete beam. If the initiation time of the breaking of a concrete beam is assumed to be $T = 20$ (770 μsec in real time), the relation of $\sigma_x/\sigma_0=2.0$ is obtained from the stress ratio curve shown in Fig.10. According to the breaking strength of the concrete beam presented in Table 2, $\sigma_0 = 3.94/2.0 = 1.97 \text{ MPa}$. As a result, the impact force generated between the hand and the concrete beam becomes 3.9 kN at least. This value is one example. The impact force slightly varies with the conditions of the different braking time and the different size of contact area, and the value of the impact force generated due to *Shyutoh-uchi* was laid from 3.9 kN to 4.5 kN.

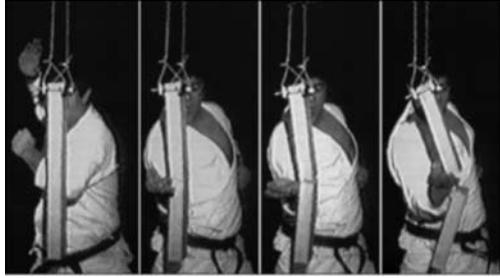


Figure 6. Successive photographs of Tameshi-wari for a concrete beam suspended in the air.

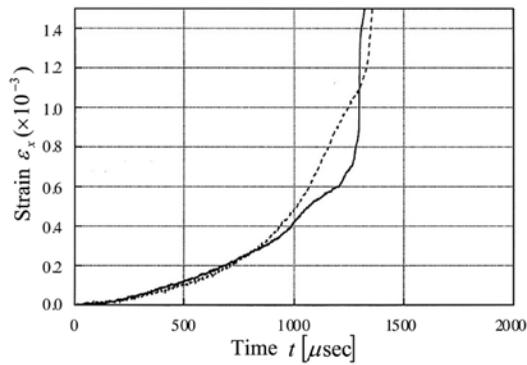


Figure 7. Impact strain responses at the bottom center of concrete beams suspended in the air.

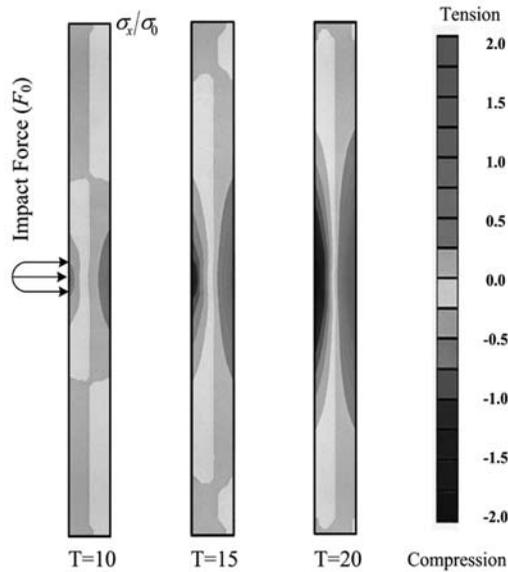


Figure 8. Distributions of dimensionless stress σ_x / σ_0 in a concrete beam at each dimensionless time.

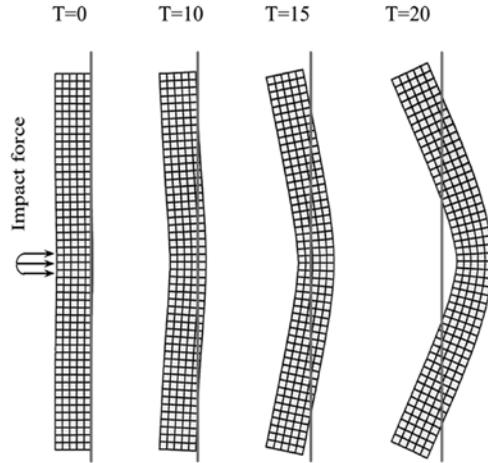


Figure 9. Successive behavior of impact bending deflection of a concrete beam subjected to impact force.

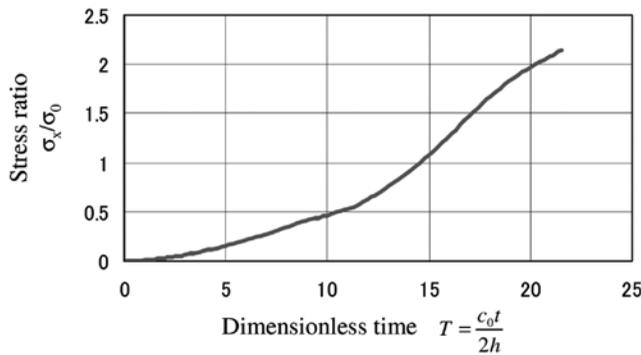


Figure 10. Variation of stress ratio σ_x / σ_0 with time at the bottom center of a concrete beam suspended in the air.

CONCLUDING REMARKS

In the present study, the power of the hand techniques in Karate-doh was discussed from the viewpoint of impact engineering by means of Tameshi-wari for concrete beams.

(1) *Tameshi-wari* by means of *Shyutoh-uchi* (sword-hand) was performed using simply supported concrete beams (thickness 5 cm, width 10 cm and length 50 cm). The breaking of the concrete beam occurred at 700~800 μ sec after the impact due to *Shyutoh-uchi*. The numerical simulation was carried out based on a dynamic finite element method using a Newmark- β method in order to understand the mechanism of the impact breaking of concrete beams subjected to the impact force generated by the hand techniques of *Karate-doh*,

(2) It was verified experimentally and analytically that the deformation mode of a beam subjected to the impact force generated by the hand techniques was clearly different from one under a static load. That is, the third mode of bending deformation of a simply supported concrete beam was dominant and the reactions at both ends of the beam were almost never generated.

(3) This suggests that the breaking of concrete beams floating in the air is quite within the bounds of possibility by means of *Tameshi-wari*. As a matter of fact, the advanced player in *Karate-doh* will be able to do it. Therefore, *Tameshi-wari* for the concrete beam suspended in the air was also tried. We succeeded to obtain the result as predicted by the numerical simulation. In addition, it was found that the impact force generated due to *Shyutoh-uchi* (sword-hand) for concrete beams was over 3.9 kN.

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