SECTION I. EVALUATION OF THE POTENTIAL FOR FLYING-OFF OF GATE COLUMN CROWNS DUE TO VERTICAL DYNAMIC DISTURBANCES

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1. Purpose: Reportedly, there are witness observations indicating that during strong earthquakes objects fly off the ground reaching notable heights. Although not substantiated by hard evidence there must be some truth in such statements which renders a quantitative study on what height a body not firmly fixed to its base can reach when subject to various types of dynamic disturbances and earthquake waves in particular. Our goal is to find causes for such behavior by numerical experiments so that if similar behavior patterns are observed during earthquake these to be judged as the result of input ground motions similar to those we use in the numerical experiments.

2. Evaluation by a mechanical model: We could evaluate the height a body can reach by analyzing the motion of a mass point. Consider a mass point sitting on top of a base point. If the base point is moved upwards with velocity v_o and then instantaneously stopped, the mass point will fly off with the same velocity. Then the maximum height H_I it can reach in the presence of gravity is, $H_I = v_0 t - gt^2/2$. The values computed from this equation are shown in Fig 1. If the velocity of the base point is instantly reversed the maximum apparent heights (separation) will be twice the values in Fig. 1.

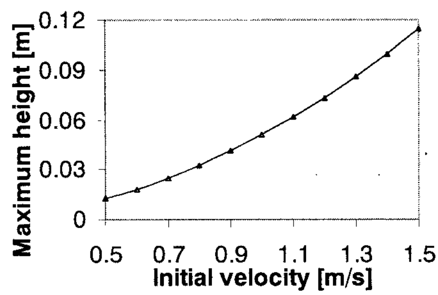

Fig. 1 Maximum flight heights

3. Numerical evaluation: The influence of dynamic amplification and flexibility has to be evaluated in order to confirm the reliability of the mass point model. The model represents, a 1.8m high concrete column with a cross section of 0.18m^2 (0.42m/0.42m) supporting a crown with dimensions 0.5m/0.5m/0.1m[1]. The lumped mass - spring model is shown in Fig. 2. The interaction between the crown and the column was modeled by two springs; one compression-only and one tension-only. The tension spring is allowed to break if the force in it reaches a specified value. The column body was modeled by compression-tension springs which were not allowed to break. In view of the expected breaking and large separation at the interface a discrete element solution procedure was employed[2]. The input motion was applied at the support level, which is fully fixed. First, the response to recorded earthquake waves was studied. The Takatori station and the JMA records from the 1995 Kobe earthquake were used. The separation at the interface was very small; in the order of 1x10^{-6}m. Then two waves of predominant frequency 80Hz and 400Hz were produced by scaling the time axis of the original Takatori wave (8Hz). The scaled velocity time-histories were kept the same as the original wave. The separation responses for the two waves are shown in Figs. 3 and 4. The separation increases significantly compared to the original

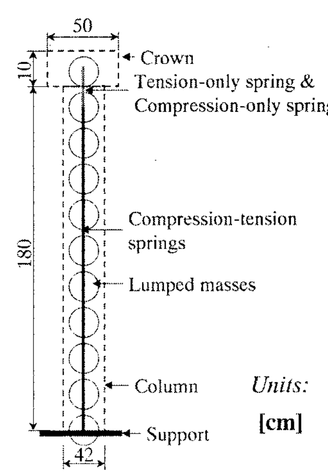

Fig. 2 Analysis model

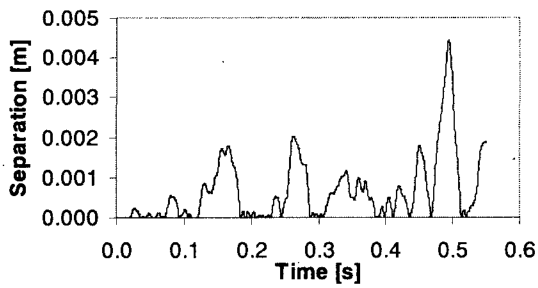

Fig. 3 Response to 80Hz wave

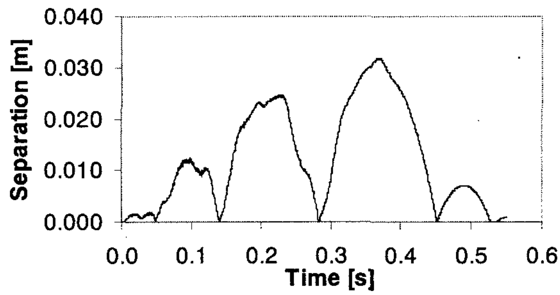

Fig. 4 Response to 400Hz wave

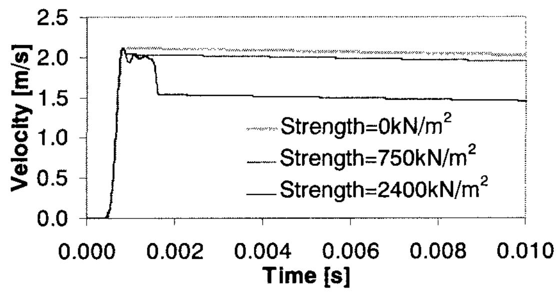

Fig. 5 Influence of interface strength

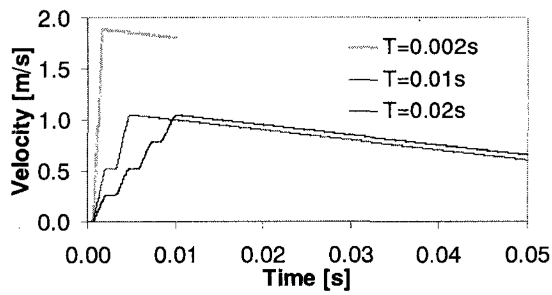

Fig. 6 Influence of pulse duration

wave, but is still negligible in absolute terms. The dynamic amplification for velocity in the case of the 80Hz wave is 1.019 and 2.56 for the 400Hz wave. The response to a constant pulse of velocity 1m/s and varying strength at the interface is shown in Fig. 5. The dynamic amplification of 2.1 is well consistent with the theoretical value of 2.0, and the decrease in the fly-off velocity with increasing strength is evident. The response to triangular pulses of varying duration and peak velocity 1m/s is shown in Fig. 6. We see that for short duration the amplification factor is quite large, and in the limit would reach the value 2.1 yielded by constant pulses. On the other hand as duration increases the amplification factor decreases and for duration 0.01s is effectively unity.

4. Conclusions:

(1)Typical earthquake waves cannot cause appreciable separation at the column-crown interface.

(2)High-frequency disturbances of above about 200Hz could cause much larger separations, but the presence of high-frequency components is not a sufficient condition for occurrence of a notable fly-off. The reason behind this is that separation occurs at the first possible occasion before reaching the potentially most powerful part of the record. Likewise, a pulse can produce a fly-off only if at its occurrence the column and the crown are in contact.

(3)The proposed simple mechanical formula provides a conservative estimate of the separation distance, except for pulses. The values predicted by the formula are small enough in absolute terms no matter they can be an order or two bigger than the numerical results.

References:

1)Sonoda K., Takada N., Kobayashi Y., Takahashi K., Sugano H., Yohochi N and Nakahara H., Verification of impulsive wave from viewpoint of jumping phenomena during the 1995 Hyogoken-Nanbu earthquake, *5th Simp. on Shock Problems of Struct.*, JSCE, pp.1-6, 2000

2)Ivanov R., *Failure Analysis of Structures by the Three Dimensional Discrete Element Method*, Ph.D. Thesis, Kobe University, 2001