3D CRASH CALCULATION OF STACK AND REACTOR BUILDING OF HTTR

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ABSTRACT

Integrity confirmation of building against the crash of flying object due to the tornado was carried out by formulas which calculate by simple shape. However, there was no study on crash calculation using complex shape such as the stack and reactor building. In this study, the crash calculation was carried out by a real shape model of High Temperature Engineering Test Reactor (HTTR) stack and reactor building using three-dimensional analysis code (VPS: Virtual Performance Solution). In the calculation, parameters of VPS were conservatively set in accordance with the formulas, which are formulated based on results of crash experiments and approved by the Nuclear Regulatory Authority. The crash calculation of stack and reactor building of HTTR was carried out using VPS. As a result, the integrity of building against the crash by stack was confirmed.

1. Introduction

After the Great East Japan Earthquakes on March 11 2011, the safety of nuclear reactors became a primary concern. In order to improve safety, the Nuclear Regulatory Authority (NRA) established regulation standards for research reactors. The NRA strengthened standards for earthquakes, tsunamis, etc., and established new standards for tornadoes, severe accidents, etc. The conventional empirical formulas can predict local destruction mode such as penetration and backside peeling against flying object of a simple shape caused by the tornado [1,2]. However, there are complex shaped buildings and constructions around reactor building, and they might crash with reactor building. The reactor building protects the internal important facilities from flying objects as outer shell. Therefore, it is important to establish a calculation method, which can predict integrity of entire building against complex shaped flying objects.

In this study, crash calculation of stack and reactor building was carried out on the assumption that the stack collapses due to tornado with a wind speed of 100m/s. In crash calculation, real shaped models of reactor building and stack are created by Virtual Performance Solution [3,4] (VPS), which is a general finite element method applied for crash of cars, aircraft and so on. Physical property values were conservatively set so that the result of VPS calculation has more conservativeness than formulas recommended by the guideline [5] and approved by NRA. The physical property values of VPS calculation was compared with the result of empirical formulas, and it was confirmed that VPS calculation is valid.

As a result of the crash calculation between reactor building and stack, ceiling of reactor building was not damaged and it didn’t affect the inside of reactor. It was confirmed that important facilities in reactor were integrity. Because stack is softer than reactor building, stack deforms and absorbs the kinetic energy.

2. Outline of HTTR

High Temperature Engineering Test Reactor (HTTR) of Japan Atomic Energy Agency (JAEA) is the first High Temperature Gas-cooled Reactor (HTGR) constructed for the purpose of establishing and upgrading HTGR technology [6].

HTTR consists of reactor building, stack and so on, and Fig.1 shows overall layout of HTTR. Reactor building, which is a reinforced concrete structure, has square shape of about 50m x 48m and is about 25m tall from the ground. Stack is a height of about 80m and constructed in northeast of reactor building, and its position is about 16m far from reactor building.

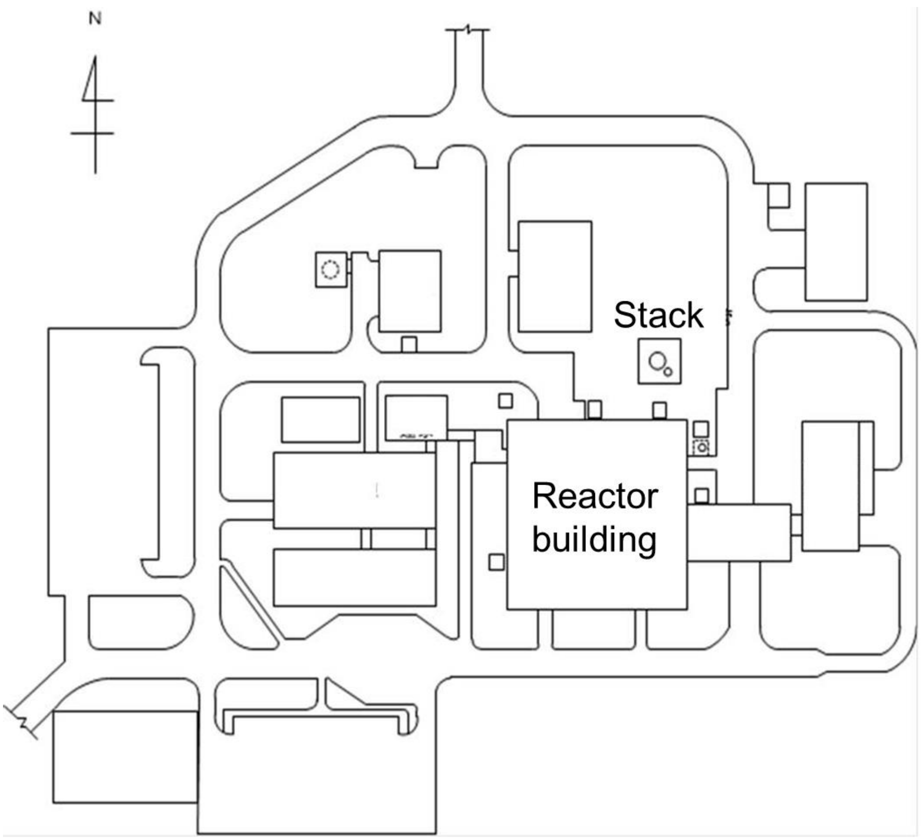

Fig.1 Overall layout of HTTR

3. Condition of Evaluation

3.1 Reactor Building and Stack

The shape, size and materials of reactor building were modeled based on completion drawing. The physical property values of steel materials were determined by Japanese Architectural Institute Standards and Japanese Industrial Standards. Wall thickness is 30cm at the thinnest place. Fig.2 shows model of reactor building.

The shapes, size and weight distribution of stack were faithfully modeled based on construction drawing. Fig.3 shows model of stack.

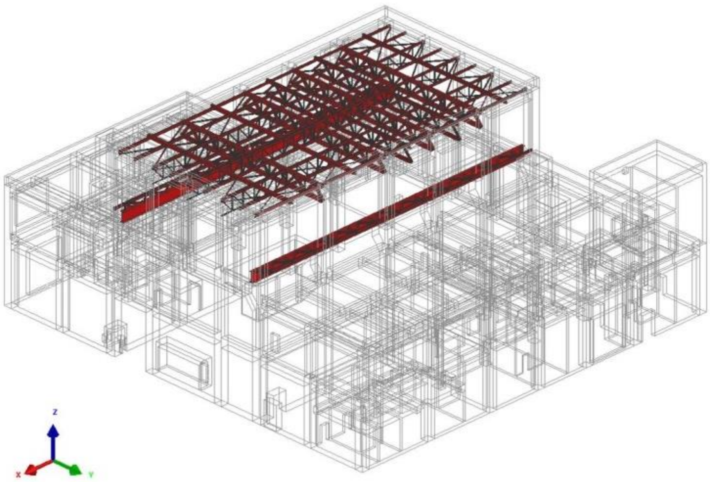

Fig.2 Model of reactor building

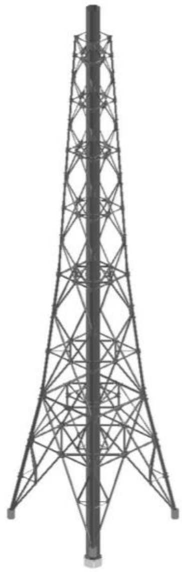

Fig.3 Model of stack

3.2 Physical Property

There is no standard of physical property values of reinforced concrete, so values were set by empirical formulas. Penetration depth is given by the modified NDRC (National Defense Research Committee) equation (1) and Degen equation (2).

$$X_c = \alpha_c \sqrt{4kWND\left(\frac{V}{1000D}\right)^{1.8}} \quad ,for \quad \frac{X_c}{\alpha_c D} < 2.0 \cdots\cdots (1)$$

$$t_p = \alpha_p D\left\{2.2\left(\frac{X_c}{\alpha_c D}\right) - 0.3\left(\frac{X_c}{\alpha_c D}\right)^2\right\} \quad ,for \quad \frac{X_c}{\alpha_c D} < 1.52 \cdots\cdots (2)$$

X_C: perforated limit [in]	α_C: 1.0 (penetration reduction factor)
k: $180/\sqrt{F_c}$	W: weight [lb]
N: 0.72 (flat-nose missile)	t_p: wall thickness to prevent perforation [in]
V: velocity [ft/s]	F_C: concrete strength [psi]
D: outer diameter [in]	α_p: 0.65 (penetration reduction factor)

Fig.4 shows the relation, which is obtained by equation (1), (2) and physical property of HTTR, between critical impact velocity and perforated limit. According to the relation, if flying objects crash with critical impact velocity (67.8 m/s or 93.8 m/s), the flying objects penetrate reinforced concrete (30 cm or 40 cm). Crash calculation between a simple shaped object and a wall was carried out by VPS, and physical property values were set so as to penetrate reinforced concrete of HTTR. The results of crash calculation with simple shaped flying object using VPS are shown in Fig. 5. Since flying object penetrates reinforced concrete at each impact velocity, it is confirmed that crash calculation using VPS has more conservativeness than empirical formulas.

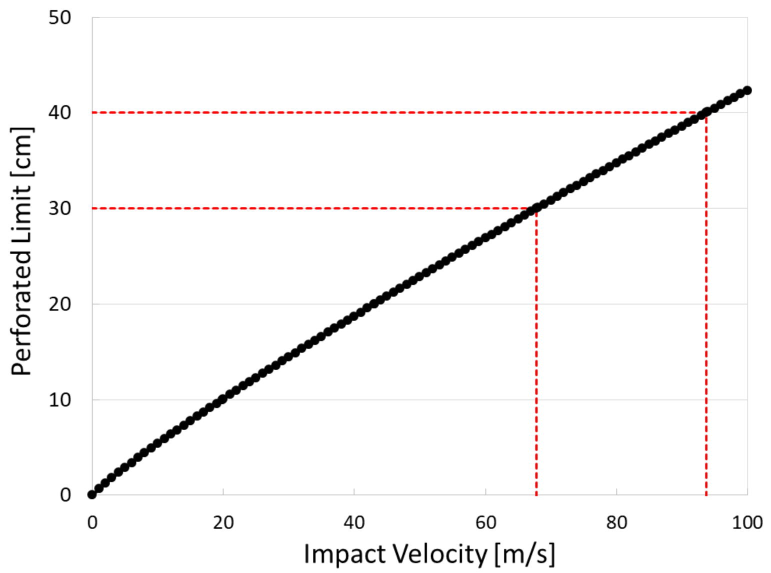

Fig.4 Relationship between impact velocity and perforated limit

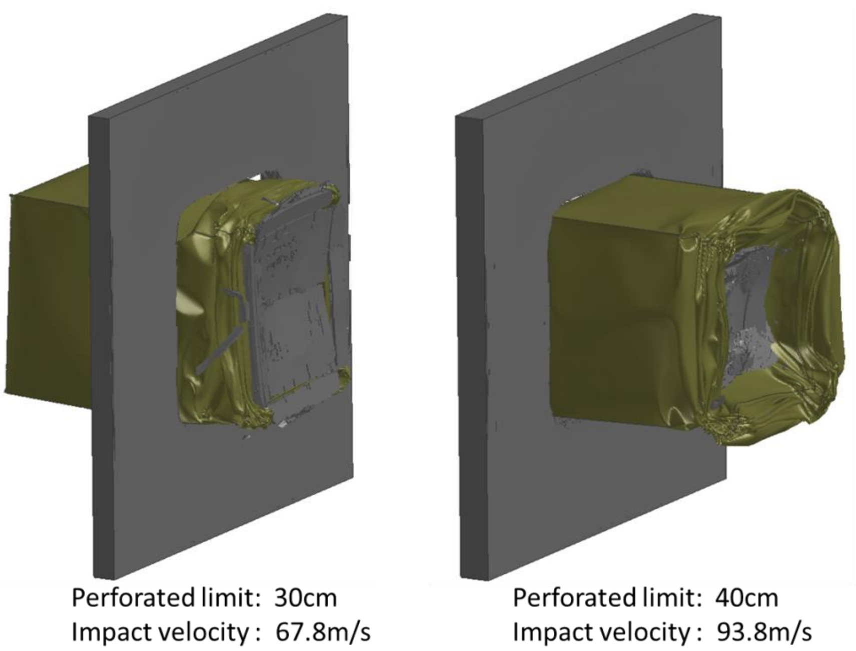

Fig.5 Results of crash calculation on conservative property values

3.3 Crash

In crash calculation, wind speed of 100m/s is continuously given to stack, and stack is collapsed. If strain of concrete member or steel frame of reactor building exceeds the threshold value due to crash, the element is lost. On the other hand, load of stack is continuously given to building, because element of stack is not lost due to crash. Stack collapses toward the containment vessel where important equipment is stored. Fig.6 shows restraint condition of column base.

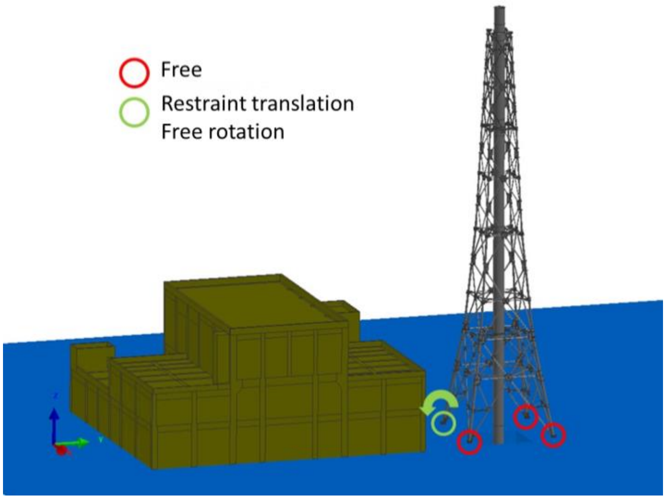

Fig.6 Restraint condition of column base

4. Result and Consideration

As a result of crash calculation, it was confirmed that ceiling of reactor building was not damaged and it didn't affect important facilities inside building. Regarding steel frame, there were no elements exceeding the strain threshold. The crash behaviour stack and reactor building is shown in Fig. 7.

In this calculation, element breakage didn't occur in the floor slab where stack crashed. As a reason for that rigidity of stack is lower than reactor. In the case of hard missile, kinetic energy is converted into strain energy of soft wall. On the other hand, in this calculation, stack is deformed largely because it is soft missile. Kinetic energy of stack is not converted into strain energy of reactor building, but it is converted into strain energy of stack itself. Fig.8 shows time history of kinetic energy and strain energy of stack and reactor building in crash calculation.

5. Conclusion

In this study, crash calculation was carried out using 3D real shape model of stack and reactor building with conservative physical property values. As a result, it was confirmed that ceiling of reactor building was not damaged and it didn't affect the inside of building. It was confirmed that important facilities in reactor were integrity. Because stack, which is soft missile, is less rigid than reactor building, and stack deforms and absorbs kinetic energy. By using this method, it becomes possible to predict the crash behaviour of entire reactor building and complex shaped flying objects.

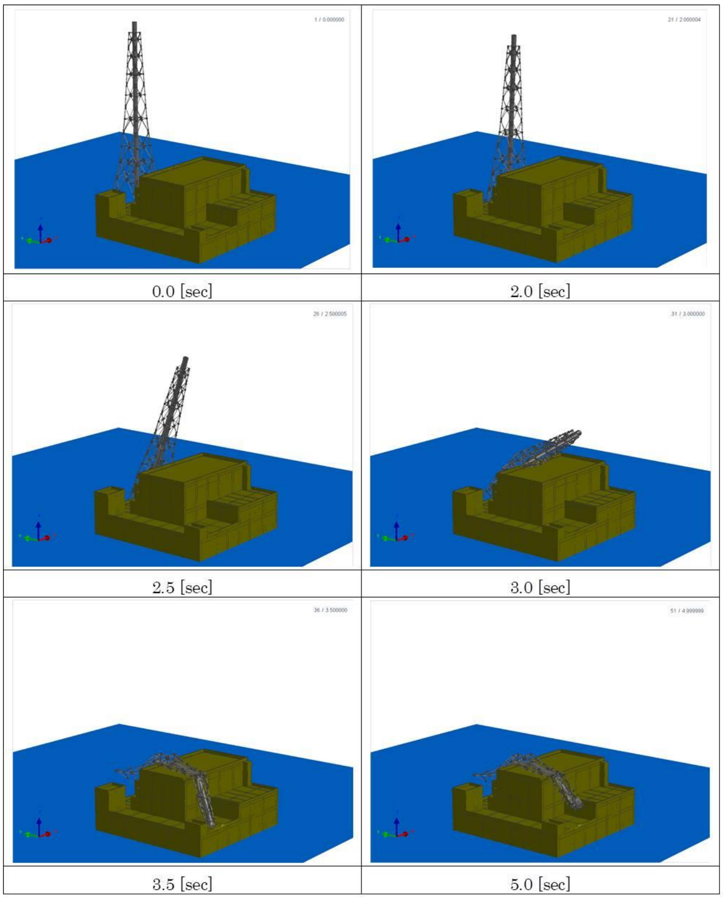

Fig.7 Crash behaviour stack and reactor building

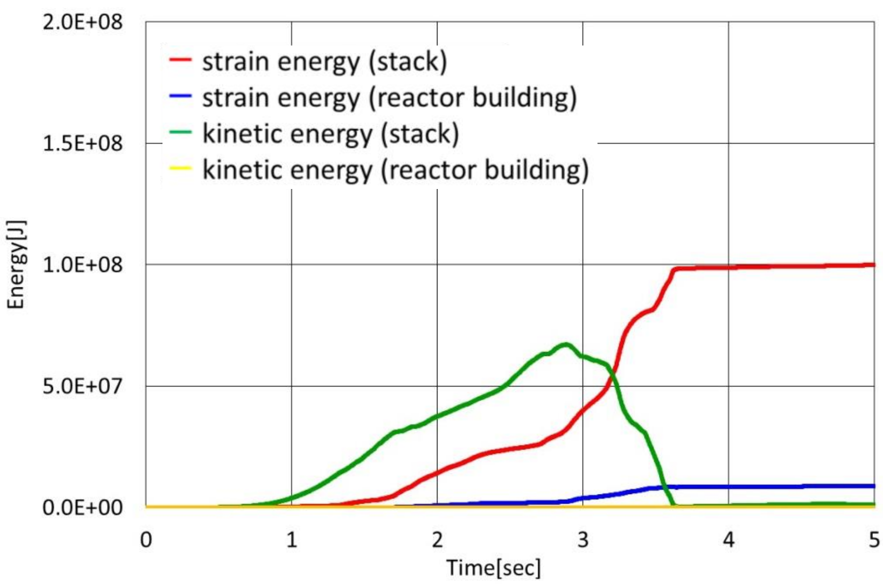

Fig.8 Time history of kinetic energy and strain energy of stack and reactor building

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