A Fundamental Study on the Lateral Impact Problems of Tubular Members

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원통부재의 횡충돌에 관한 기초적 연구

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요 약

해양구조물은 이동의 제약성으로 인하여 선박등과 같은 물체와 충돌할 가능성이 높다. 일반적으로 설계단계에서는 소규모 충돌을 고려하는 것이 바람직할 것이다. 이러한 가능성 있는 사고를 대비한 해양구조물 설계를 위하여 이들 구조물의 주요 요소인 원통부재의 충돌에 대한 동적거동을 폭넓게 이해하는 것이 중요하다고 할 수 있다.

소규모 충돌에 충분히 견딜 수 있는 원통부재를 설계하기 위하여 충격하중의 시간에 따른 원통부재의 손상정도를 추정할 필요가 있다. 본 논문에서는 3차원 탄소성 대변형 충돌 문제 해석용 프로그램 DYNA3D를 이용한 수치 시뮬레이션을 통하여 원통부재의 횡충돌에 대한 동적거동을 조사하고자 한다.

Abstract

Offshore structures are exposed to higher probability of collision with ship because of their limited mobility. In general, the consequence of the collision is reported to be relatively small and it is desirable to consider minor collisions in the design stage. It is important to have a

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comprehensive understanding of the dynamic responses of a tubular, their main member, under collision to design offshore structure against possible accidents.

It is needed to estimate the probable extent of damage of a tubular, depth of dent, affected by the time history of impact load in order to design a tubular strong enough for collision. In this paper, dynamic behaviors of a tubular due to the lateral impact are investigated through the numerical simulations with hydrocode DYNA3D, a three dimensional elasto - plastic large deformation impact contact problem analyzing program.

I. INTRODUCTION

There has been a growth of interest in offshore collision problems with ship such as attendant vessel, loading tanker and passing vessel etc., whose consequences have been reported to be relatively small[1-3]. A collision with an offshore structure can be classified into major and minor based on the extent of its damage. A minor collision will result in repairable local damage of the structure, while a major one will damage it globally. It is desirable to consider minor collisions in the design stage, and necessary to predict their probability and the probable extents of damage. It is still premature to predict the actual collision probability and the probable extents of damage.

By the assumptions commonly adopted in the static approach dynamic effects are insignificant and the elastic strain energy stored in the colliding bodies is negligible. According to the results of the recently published works these assumptions cannot be valid[4]. It would be premature to draw any firm conclusions from the results of the limited cases, but it can be suggested that dynamic elastic - plastic analyses must be employed in predicting the consequences of offshore collisions. More reliable simulation methods are necessary, owing to the complexity and the uncertainty in the nature of offshore collision.

The above mentioned crash or impact problems have a dominant characteristic of large deformation for short time scales with dynamic material plasticity. In this study, code DYNA3D[5] is used to numerically simulate the dynamic response of a tubular under collision of rigid body. Lateral impact simulations were validated with experimental results[6], which were conducted on small - scale tubes having simply supported roller conditions[7].

The aim of this study is to perform numerical simulations of the probable extent of damage of unstiffened tubular subjected to lateral impact with code DYNA3D, and to establish a comprehensive understanding of the dynamic responses to a tubular under collision for next performing systematic parametric studies to design offshore structure. Strain - rate sensitivity of the material and other dynamic effects upon the response of a tubular under lateral impact have been considered.

Ⅱ. NUMERICAL SIMULATIONS OF COLLISION WITH RIGID BODY

Numerical simulations of a tubular with impact of ship are performed to examine the dynamic effect. Boundary conditions of a tubular specimen are simply supported roller ones, allowing free rotation and axial movement of the ends but no lateral movement. Striker ship is idealized to the bulbous bow and cylinder. Bulbous bow is modeled again as a half of sphere again. Tubular has the following dimensions ; 1.5m outer diameter, 30mm thickness, 20m length. Diameter of sphere is 1.0m and cylinder is mounted to the sphere whose density adjusts the striker mass. Young's modulus, Poisson's ratio and density of tubular and striker sphere for numerical simulations are 210 GPa, 0.3 and 7850kg/m^3, respectively.

The relative mass of struck and striker is important factor in the collision problem. In this study the mass and velocity of striker are only varied, while the ones of struck tubular are assumed to be fixed except yield stress. Sphere is assumed to be rigid and to impact at the midsection of a tubular along the length. A quarter of numerical specimen is modeled using symmetric condition, and a half of model is shown in Fig. 2.1(a).

Material type of strain rate dependent plasticity is employed for examining the material dynamic effect. A relationship for the calculation of dynamic yield stress proposed by Cowper and Symonds[8] is implemented to the material type of DYNA3D. It relates the dynamic yield stress σ_Y in the case of a uniaxial stress system with stain rate $\dot{e}$ through the following expression

$$\frac{\sigma_Y}{\sigma_o} = 1 + \left(\frac{\dot{e}}{D}\right)^{1/p} \tag{2.1}$$

where σ_o is the static yield stress. For mild steel, D equals 40.4 s^{-1} and p is equal to 5.

The static inelastic material behavior, relationship of equivalent stress and equivalent plastic strain, is modeled as the following nonlinear isotropic hardening law with an exponential (saturation) part

$$\sigma(\bar{e}^p) = \sigma_o + (\sigma_u - \sigma_o)(1 - e^{-\gamma\bar{e}}) \tag{2.2}$$

where σ_u is the static ultimate stress, γ is the initial rate of exponential hardening, and the parameter $\bar{e}$ is a shifted equivalent plastic strain, given by the expression

$$\bar{e} = \begin{cases} 0 & 0 \le \bar{e}^p \le \bar{e}_{sh} \\ \bar{e}^p - \bar{e}_{sh} & \bar{e}_{sh} \le \bar{e}^p \end{cases} \tag{2.3}$$

where $\bar{e}_{sh}$ is the length of the plastic plateau.

To examine the effect of material properties of tubular specimen to impact problem two types of material constants are used : Type 1(σ_o=250MPa, σ_u=400MPa), Type 2(σ_o=415MPa, σ_u=610MPa). $\bar{e}_{sh}$=0.02 and $\bar{e}_u$=0.5 for both types, where $\bar{e}_u$ is the plastic strain at failure. To examine the dynamic effects of impact problems its velocity is increased instead of decreasing its mass keeping the same intial kinetic energy. Four Scenarios are considered, as shown in Table 2.1

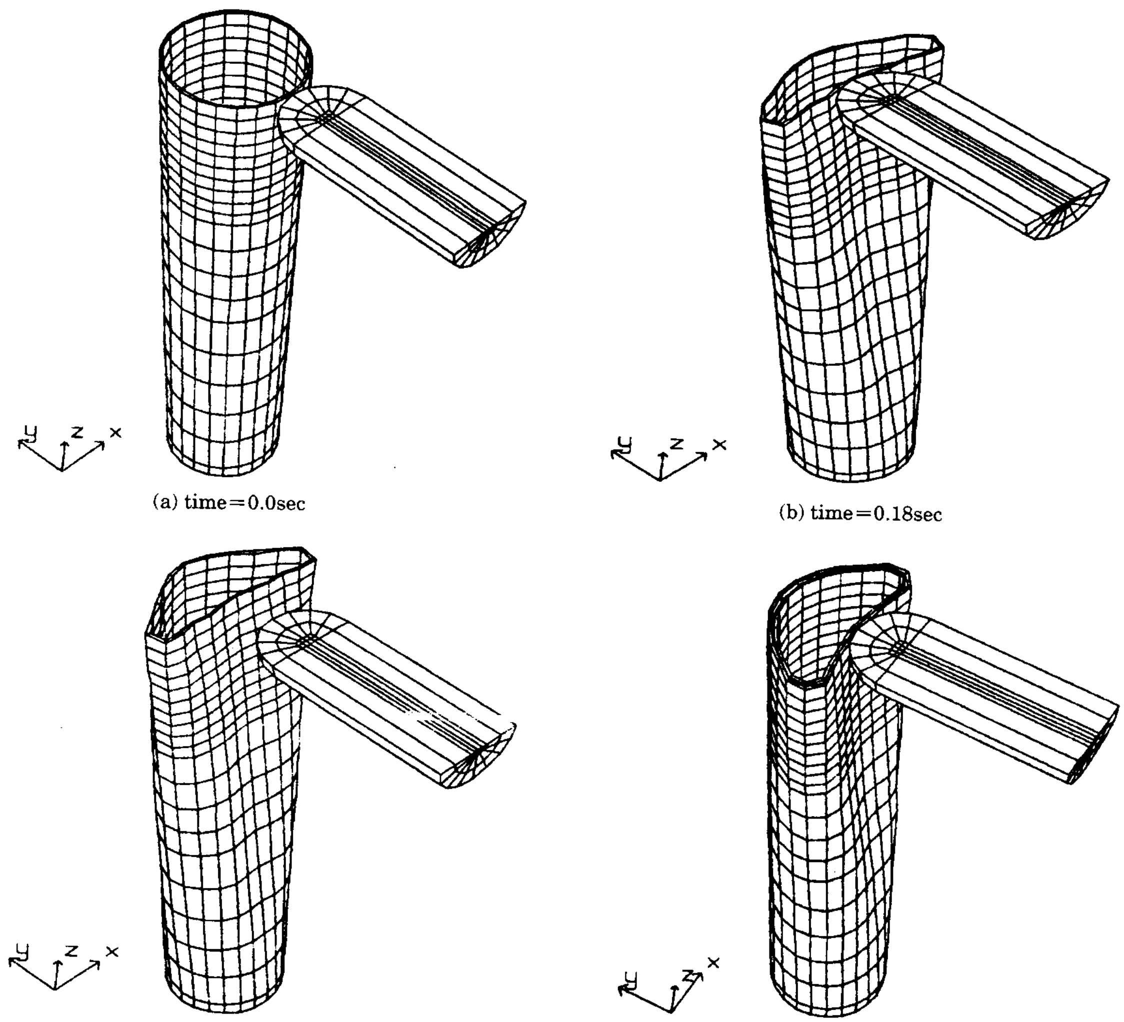
Table 2.1 Description of 4 scenarios

	Velocity(m/s)	Mass(ton)	Initial Kinetic Energy(MN – m)	Material Type
Scenario1	5.0	20	0.25	Type 1
	10.0	5		
Scenario 2	5.0	20	0.25	Type 2
	10.0	5		
Scenario 3	5.0	20	0.25	Type 2
	7.5	20	0.5625	
	10.0	20	1.0	
Scenario 4	10	20	1.0	Type 2
	20	5		
	30	2.222		

Halves of the deformed configuration at the maximum dent and after rebound of typical case, 10 m/s and 20 ton, among the scenarios are shown in Figs. 2.1(b) and (c). Time history of effective stress at the point of impact of tubular, time history of depth of dent at the midsection of tubular, time history of velocity of striker and time history of kinetic energy of striker for each Scenario are presented at Figs. 2.2 – 2.5, respectively. These results are summarized in Table 2.2.

Table 2.2 Results of numerical simulation for each Scenario

		Effective Stress(MPa)		Depth of Dent(mm)		Velocity(m/s)		Kineticy ×1/4(MN – m)	
		Max	Min	Max	Min	Max	Min	Max	Min
Scenario 1	5m/s 2t	261	31.0	554	446	5.0	– 1.02	0.0625	0.0026
	10m/s 5t	276	24.6	469	377	10.0	– 1.50	0.0625	0.0014
Scenario 2	5m/s 20t	422	10.3	476	306	5.0	– 1.50	0.0625	0.0056
	10m/s 5t	425	7.0	406	242	10.0	– 2.22	0.0625	0.0031
Scenario 3	5.0m/s 20t	422	10.3	476	306	5.0	– 1.50	0.0625	0.0056
	7.5m/s 20t	430	6.8	713	526	7.5	– 1.70	0.1406	0.0072
	10.0m/s 20t	449	3.2	975	794	10.0	– 1.93	0.2500	0.0092
Scenario 4	5.0m/s 80t	438	18.7	1120	959	5.0	– 0.98	0.2500	0.0095
	10.0m/s 20t	449	3.2	975	794	10.0	– 1.93	0.2500	0.0092
	20.0m/s 5t	590	33.3	819	627	20.0	– 2.55	0.2500	0.0040
	30.0m/s 2.2t	599	52.4	702	521	30.0	– 2.96	0.2500	0.0024



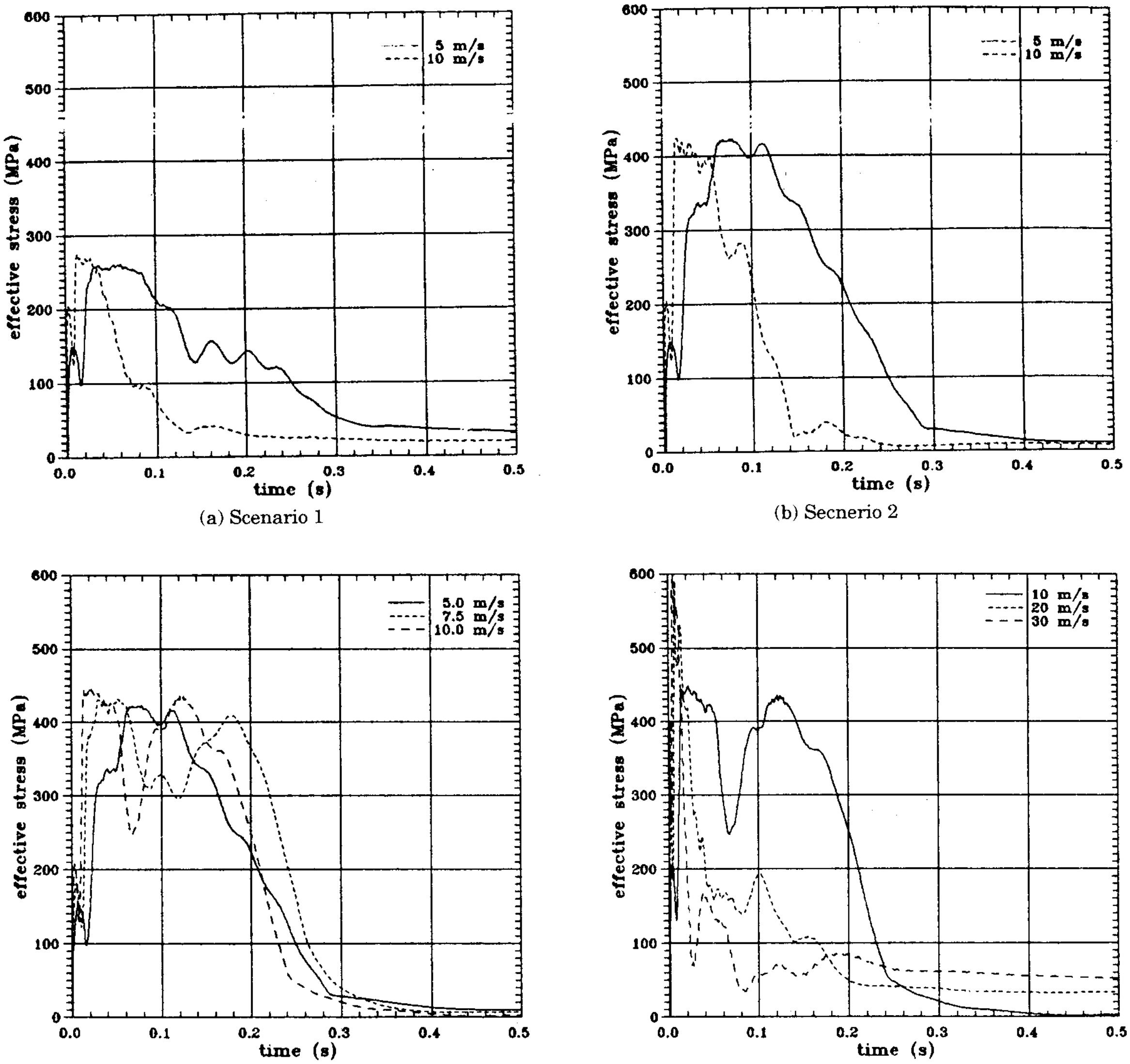
(a) time=0.0sec (b) time=0.18sec

(c) time=0.5sec (d) time=0.12sec

Fig. 2.1 Numerical meshing and deformed geometry

It can be seen from Fig. 2.2 and Table 2.2 that the peak of effective stress at the point of impact is increased a little with an increase of velocity of striker at the same lower initial kinetic energy in Scenario 1 and 2, and also increased somewhat with increasing velocity at the same mass of striker in Scenario 3. The same phenomenon can be found in Scenario 4, but very big peak value occurs at high velocity, for example, over 20 m/s of velocity in this study. This symptom can be referred to the effect of strain rate dependent plasticity of material. Even the same condition is applied to the Scenarios 1 and 2, it can be seen that the peak of effective stress highly depends on the strength of material from Figs. 2.2(a) and (b). From these results we may say that the stress of struck material greatly depends on the high speed of striker and the strength of struck material.

On the contrary to the case of the effective stress, the depth of dent at the midsection of tubular



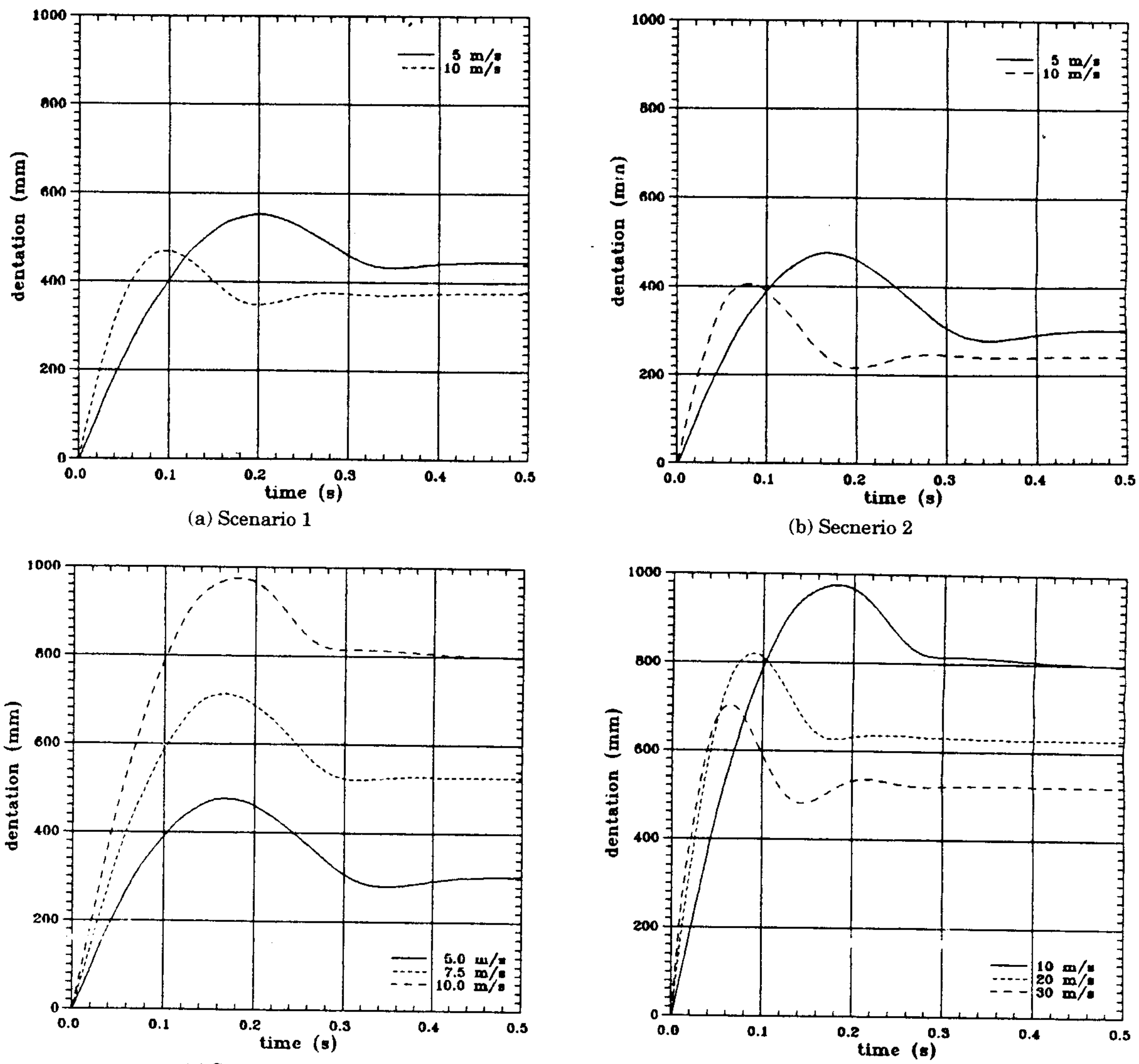
(a) Scenario 1　(b) Secnerio 2

(c) Scenario 3　(d) Secnerio 4

Fig. 2.2 Time history of effective stress at a point of impact of tubular

can be seen to be greatly dependent on the mass of striker at the same kinetic energy, and on the speed of striker at the same mass of striker, as shown in Fig. 2.3 and Table 2.2. Compared to Scenario 1 and 2, high strength of material can sustain more the deformation from the impact than low strength of material. Therefore, deformation by impact is more affected by the increase of mass at the same kinetic energy, and largely by the speed of striker at the same mass of striker, and finally by the strength of material. The residual deformation also has the same phenomenon.

As expected, rebounding velocity of striker is increased a little with an increase of initial impact velocity of striker, as shown in Fig. 2.4 and Table 2.2. Rebounding velocity is also increased a bit



(a) Scenario 1

(b) Secnerio 2

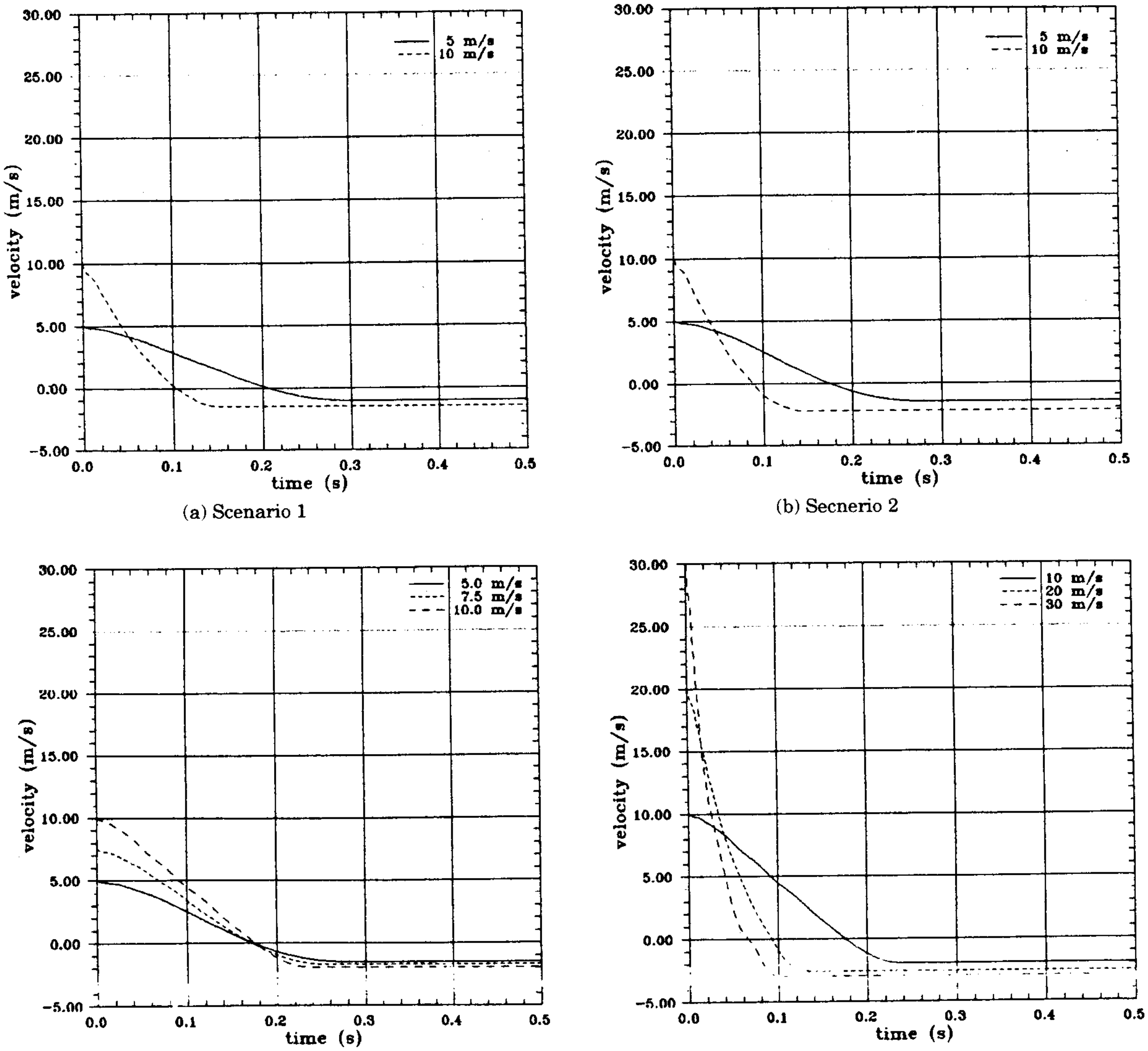
(c) Scenario 3

(d) Secnerio 4

Fig. 2.3 Time history of depth of dent at a midsection of tubular

with decreasing mass of striker at the same initial velocity. Striker is rebounded more quickly as initial velocity is increased at the same initial kinematic energy, while striker is rebounded at the same time in the case of the same mass of striker. The high strength of struck material rebounds a striker somewhat faster than the low strength.

Initial kinetic energy of striker, $E=1/2\ MV^2$, can be determined by the mass, impact velocity, impact geometries, etc. Since rebounding velocity of striker is not proportional to the initial impact one, kinetic energy after rebound can be found to be affected more by the mass of striker at the same kinetic energy, as shown in Fig. 2.5. and Table 2.2. Kinetic energy after rebound must be



(a) Scenario 1

(b) Secnerio 2

(c) Scenario 3

(d) Secnerio 4

Fig. 2.4 Time history of velocity of struck tubular

affected more by the speed of striker at the same mass. Since striker is relatively rigid, there is no deformation of striker during impact. Therefore, it may be said that the total absorbed energy of tubular and kinetic energy of striker are the same, and no increase occurs from the impact.

To examine the effect of strain rate of struck material, the dynamic yield stress is not considered in the case of 20m/s and 5 ton in Scenario 4. In this case, two types of static inelastic material behavior is set : Type 1 ($\bar{e}_{sh}=0.02$) and Type 2 ($\bar{e}_{sh}=0.00$). Their results are shown in Fig. 2.6. It can be seen that the peak effective stresses are 415MPa in Type 1 and 442MPa in Type 2, and the depths of dent are increased by 26mm in Type 1 and 19mm in Type 2. Therefore increase of stresses

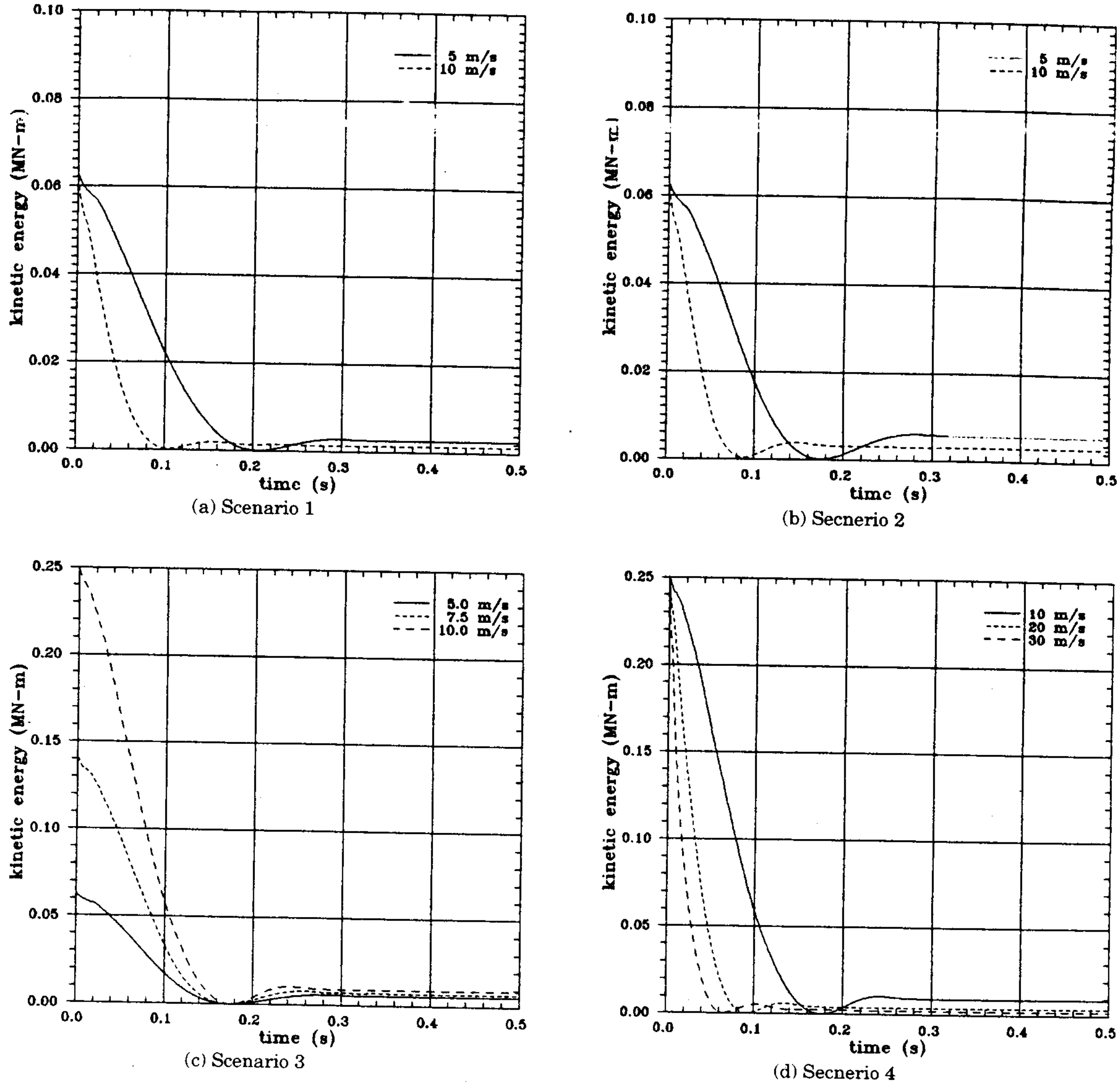
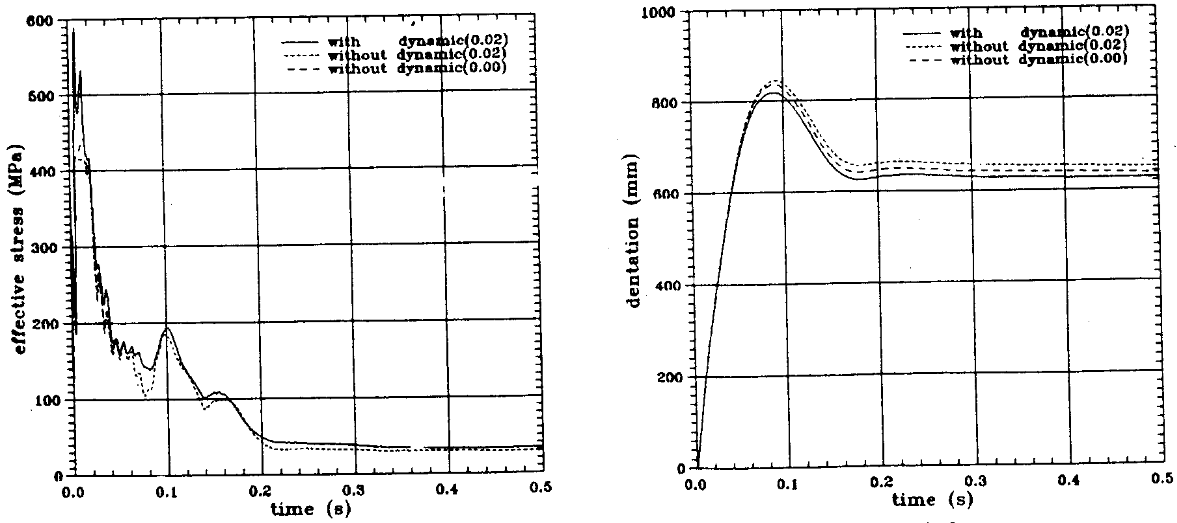


Fig. 2.5 Time history of kinetic energy of striker

around area near to the point of impact by the effect of strain rate gives somewhat resistance to deformation from the impact. Since the effective plastic strain is 0.01389 at the peak stress in Type 1, static inelastic stress must be 415MPa and is on the yield plateau. It can be obtained that its strain rate is approximately 0.54 s^{-1} using Eq. (2.1).

Pile is usually inserted in the leg of offshore structure to fix the whole structure against the foundation. To examine the effect of pile in the leg on the impact, the following pile is considered inside a tubular : outer diameter 1.38m, thickness 30 mm and space 30 mm between pile and tubular. The case of 10m/s and 20 ton in Scenario 4 is performed, and its effect and the deformed configuration



(a) Scenario 1 (b) Secnerio 2

Fig. 2.6 Effect of strain rate - dependent plasticty

at maximum dent are shown in Table 2.3 and Fig. 2.1(d), respectively. It can be seen that pile has a great effect on the resistance to the impact.

Table 2.3 Effect of pile on the impact in the case 10m/s and 20 ton

	Effective Stress(MPa)		Depth of Dent(mm)		Velocity(m/s)		Kineticy × 1/4(MN · m)	
	Max	Min	Max	Min	Max	Min	Max	Min
without pile	449	3.2	975	794	10.0	- 1.93	0.2500	0.0092
with pille	465	4.7	648	467	10.0	- 2.11	0.2500	0.0111

Ⅲ. SUMMARY AND CONCLUSIONS

In this paper, dynamic behaviors of a tubular under collision are investigated through the numerical simulations with code DYNA3D. This numerical simulation with code DYNA3D can be a powerful tool to establish a comprehensive understanding of the dynamic behavior of collisions problem and to estimate the probable extent of damage with accuracy, through the validity of this code by comparing with the published experimental results. Even this code plays a good numerical simulator to collision problems, many efforts are needed to use, especially in the implementation of an exact material modeling.

The following conclusions can be drawn from the general parametric studies :

(1) The stress of struck material greatly depends on the high speed of striker and the strength of

struck material.

(2) Deformation by impact is more affected by the increase of mass at the same kinetic energy, and largely by the speed of striker at the same mass of striker, and finally by the strength of material.

(3) Rebounding velocity of striker is increased a little with an increase of initial impact velocity of striker, and also with decreasing mass of striker at the same initial velocity.

(4) Striker is rebounded more quickly as initial velocity is increased at the same initial kinematic energy, while striker is rebounded at the same time in the case of the same mass of striker.

(5) Kinetic energy after rebound can be found to be affected more by the mass of striker at the same kinetic energy, and by the speed of striker at the same mass.

(6) Increase of stresses around area near to the point of impact by the effect of strain rate gives somewhat resistance to deformation from the impact.

More basic numerical simulations for the relationship of striker mass and struck mass, and the effect of deformable striker etc., will be performed to the future study. Based on these basic informations, systematic parametric studies will be considered for the design of offshore structure under collision : The effects of size and thickness of a tubular, type and size of its stiffener and boundary conditions are examined with respect to the mass and the initial velocity.

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