様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科学研究費助成事業　　研究成果報告書

令和　元 年　 ６ 月 １２ 日現在

機関番号：１５１０１
研究種目：基盤研究(B)（一般）
研究期間：2014～2018
課題番号：２６２８９０５６

研究課題名（和文）円筒の面外変形と底板の部分浮上りの連成を考慮した液体円筒タンクの耐震設計法の構築

研究課題名（英文）Development of seismic design method of liquid storage tanks considering combined effects of out-of-round deformation of the tank shell and partial uplift of the tank bottom plate

研究代表者

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交付決定額（研究期間全体）：（直接経費）　　12,300,000円

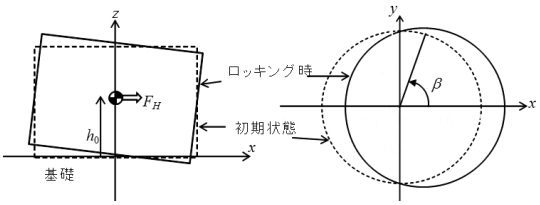
研究成果の概要（和文）：地震時に無アンカー平底円筒貯槽に生じる浮上り現象を説明する動力学モデルを考案し、同モデルに適用する内容液のロッキング有効質量やロッキング－バルジング有効質量を、数学的に定量化し、タンクの固有周期に応じた地震応答スペクトルの値に基づいて、簡易に浮上り応答を算出する手法を考案した。また、円筒貯槽の側板の面外変形が、底板の浮上りを助長することを、小型貯槽模型を用いた振動実験により明らかにした。

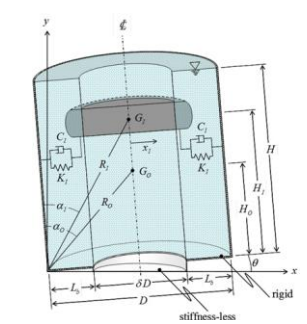
研究成果の学術的意義や社会的意義
本研究で開発した動力学モデル、各種有効質量や簡易浮上り応答計算法は、同様のものがこれまでにない為、それらを考案できた学術的意義は大きい。一方、簡易浮上り応答計算法により、平底円筒貯槽の浮上り量を、応答スペクトル値に基づいて手計算で求められる様になったので、平底円筒貯槽の耐震設計の高度化に寄与できた社会的意義は大きい。更に、円筒貯槽の側板の面外変形が、底板の浮上りを助長することを明らかにしたことは、今後この分野の発展の必要性を示した意味で、学術的な意義は大きい。

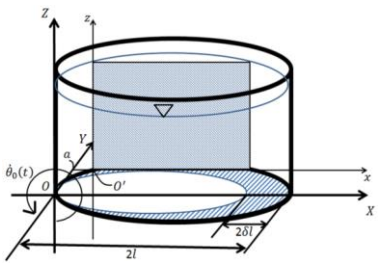
研究成果の概要（英文）：This research proposed a dynamical model that describes uplift of unanchored upright cylindrical tanks, mathematically quantified the effective mass of liquid for tank rocking motion and that for rocking-bulging interaction motion and developed a simplified calculation for evaluating uplift of tanks based on the ordinates of response spectrum corresponding to tank's natural period. Moreover, this research clarified that out-of-round deformation of tank shell enhanced uplift of the tanks based on the shaking table tests with small scaled tanks.

研究分野：耐震工学

キーワード：面外変形～浮上り連成


ロッキング時
初期状態
基礎


stiffness-less
rigid


2l
2δl

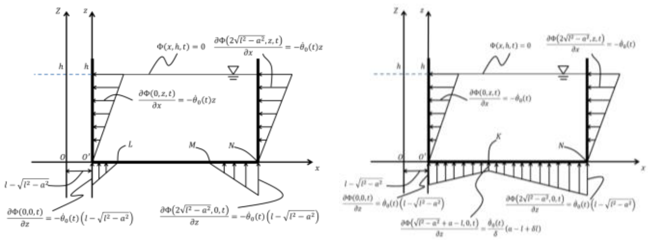
(1) SMR 8M!5

1M x O

$\dot{\theta}_0(t)$ M• 2l h 2δl δ

0 δ 1 b x a

M V M• x a K W 2 a b 8(tK2 b K 8



a b

K b 3 bK

5n8b/b03M3b 0

b/b($P(x,z,t)$ b0 u K3M

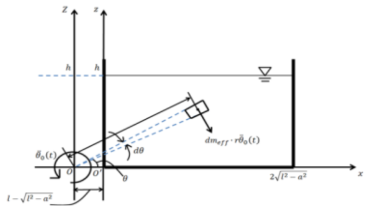
b 0(8Mb5.8 4M

M)t4M 0(MmA0bEb M b4M

AI 4 b0(b0bEbuS

b0bEbM 0(b 2A5O K

M b Mb 2A5 M_r @r b



$$\rho_{eff}(r,\theta) = -\frac{1}{r^2\ddot{\theta}_0(t)} \cdot \frac{\partial P(r,\theta,t)}{\partial \theta} \quad q$$

$$M_r = f_r M_{Total} \quad r$$

SK

$$f_r = \frac{1}{l^2 h\pi}\left[\int_0^h \int_0^{2\sqrt{l^2-a^2}} \int_{-(l-\delta l)}^{l-\delta l} f_A(x,z)\,da\,dx\,dz + 2\int_0^h \int_0^{2\sqrt{l^2-a^2}} \int_{l-\delta l}^{l} f_B(x,z)\,da\,dx\,dz\right]$$

3 0(8Mb5.8

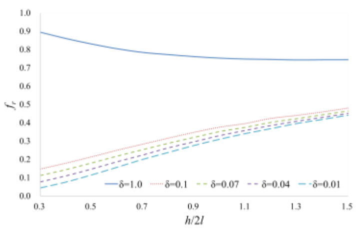
bKuSb Mb2A5b

I $(h/2l)$bM (b δ

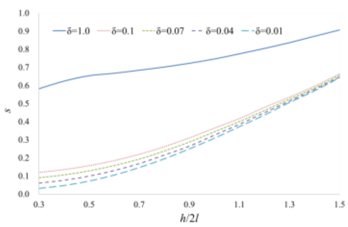
a 2A5 b2!

N! O K

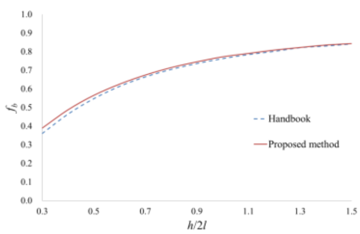
M @ b



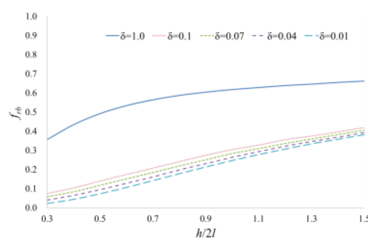
4 a 2A5



4 b



5 a 2A5



5 b 2A5

M b/b M

b 2A5 M_b K s M‰

W b

M_{rb} K t

$(h/2l)$b2A5M K/KKSb5 a

4 2A5 bI $(h/2l)$b

δ

b

$$M_b = f_b M_{Total} \qquad f_b = \frac{1}{l^2 h\pi}\left[\int_0^h \int_0^{2\sqrt{l^2-a^2}} \int_{-l}^{l} f_{b1}(x,z)\,da\,dx\,dz\right]$$

$$M_{rb} = f_{rb} M_{Total} \qquad f_{rb} = \frac{1}{l^2 h\pi}\left[\int_0^h \int_0^{2\sqrt{l^2-a^2}} \int_{-(l-\delta l)}^{l-\delta l} f_A(x,z) f_{b1}(x,z)\,da\,dx\,dz + 2\int_0^h \int_0^{2\sqrt{l^2-a^2}} \int_{l-\delta l}^{l} f_B(x,z) f_{b1}(x,z)\,da\,dx\,dz\right]$$

(2)

SMR

$(\ddot{x}_1 + \ddot{z}_H)_{max} = S_{AH}^{ratio}(T_b, h_b)(\ddot{z}_H)_{max}$

$$(\ddot{x}_1 + \ddot{z}_h) = \left\{S_{AH}^{ratio}(T_b, h_b)(\ddot{z}_H)_{max}\right\} - \frac{m_{rb}}{m_b} H_{rb}\ddot{\theta} - \frac{m_{rb}}{m_b}\left\{\frac{S_{AH}^{ratio}(T_b, h_b)(\ddot{z}_H)_{max}}{\omega_b} + \frac{D}{2}\right\}\dot{\theta}^2$$

$$\dot{\theta} = \frac{\left(-b \pm \sqrt{b^2 - 4ac}\right)}{2a}$$

$$a = m_{rb}\left[S_d + \frac{D}{2}\right]\dot{\theta}^2$$

$$b = -2m_{rb}{}^2 H_{rb} S_v \left[S_d + \frac{D}{2}\right] \cdot \left\{m_{rb}\left[S_d{}^2 + DS_d\right] + (I_{rf} + I_{sh} + I_r) + (m_{rf}R_{rf}^2 + m_{sh}R_{sh}^2 + m_r R_r^2)\right\}^{-1} \dot{\theta}$$

$$c = m_{rb}H_{rb}\left\{m_{rb}\left[S_d{}^2 + DS_d\right] + (I_{rf} + I_{sh} + I_r) + (m_{rf}R_{rf}^2 + m_{sh}R_{sh}^2 + m_r R_r^2)\right\}^{-1} \cdot \left[m_b H_b S_a - (m_{rf} + m_{sh} + m_r)gD/2 + (m_{rf}H_{rf} + m_{sh}H_{sh})(\ddot{z}_H)_{max}\right] - \left\{m_b S_a + kS_d\right\}$$

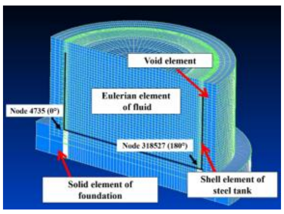
51.5m 28.8m 0.47 t/m³

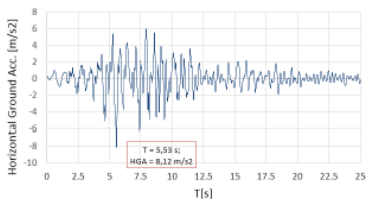
702

Kobe-NS

δ

δ=7.7%





Kobe-NS

Bottom plate uplift		Heights of the gravity centers	
Max uplift displ. $d_{z,max}$	0.704 m	H_{sh}	11.094 m
		H_r	25.307 m
Max uplift width $w_{x,max}$	3,98 m	H_b	10.809 m
		H_{rb}	22.274 m
Effective Masses		**Angles between vertical line y and R**	
m_b	17.488x10⁶ kg	α_b	67.23 rad
m_r	6.459x10⁶ kg	α_r	43.58 rad
m_{rb}	4.306x10⁶ kg	α_{rb}	45.97 rad
m_{sh}	3.866x10⁵ kg	**Moments of inertia of the masses**	
m_{bp}	7.588x10⁴ kg		
m_{rf}	0.0 kg	I_{sh}	4.56x10⁸ kg.m²
Lengths between origin and gravity centers		I_r	5.215x10⁹ kg.m²
		Dynamic bulging properties	
R_{sh}	28.039 m		
R_r	34.933 m	T_b	0.4 s
R_b	27.926 m	k_b	4.310x10⁹ kg/s²
R_{rb}	32.051 m	h_b	0.05

Responses of interest	Symplified Analisys	Numerical Analysis
Angular acc. $\ddot{\theta}$ [rad/s²]	0.202	0.240
Angular vel. $\dot{\theta}$ [rad/s]	-2.570	0.06
Abs. response acc. for bulging motion $(\ddot{x}_1 + \ddot{z}_H)_{max}$ [m/s²] (including rocking effects)	16.82	16.5
Abs. response acc. for bulging motion $(\ddot{x}_1 + \ddot{z}_H)_{max}$ [m/s²] (not including rocking effects)	20.14	/

(3)

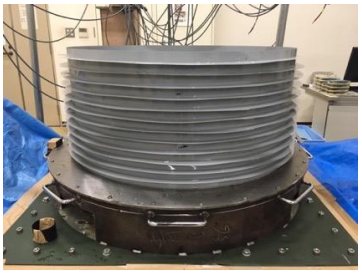
89.0m 28.9m

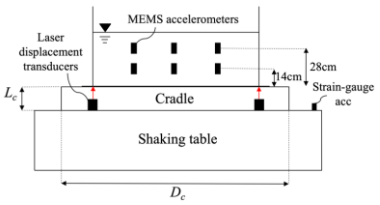
1/3 0.0214m 9%Ni LNG 1/100

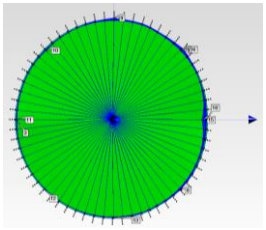
0.86 m 0.28 m 0.0003 m

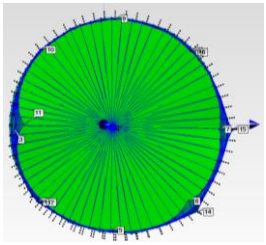
0.0005 m

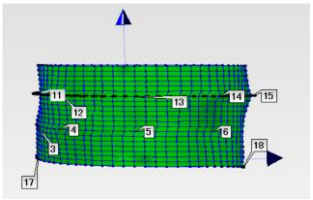
0.01m 0.0005 m 0.03m











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