

SEISMIC RISK MITIGATION OF INDUSTRIAL PLANTS THROUGH SMART SENSORS

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INTRODUCTION & MOTIVATION

- Process plants are complex systems which includes a numerous components such as tanks, piping system, vessels etc.
- Due to the nature of these raw materials that are treated in petrochemical plants, they are thesecond most vulnerable type of industrial installation after nuclear plants when subjected to Na-Tech events (especially earthquakes).
- Approximately 8% of total accidents in industrial facilities are caused by earthquakes
- It is noteworthy that whilst several aspects in terms of design and analysis are still unresolved, code-compliant methods demonstrated to result in very poor predictions and to be often dated and inadequate.
- The seismic behaviour of industrial facilities was intensively studied with numerical models, but there is a lack of experimental test in literature.
- Seismic behaviour of support structures in major hazard industrial plants is therefore of paramount importance.

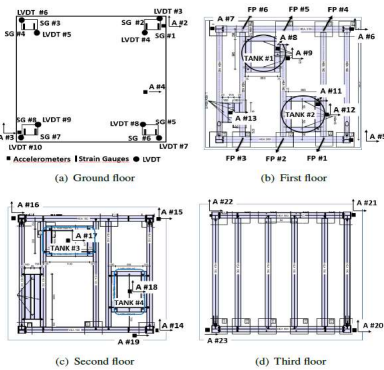


Kocaeli, Turkey, 1999

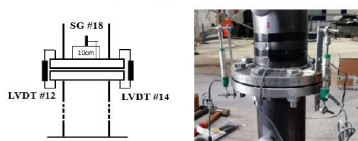
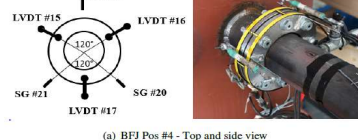


Pacific Coast of Tohoku Earthquake (Mw9.0) Japan, 2011

MOCK-UP DESCRIPTION & SENSORS LAYOUT



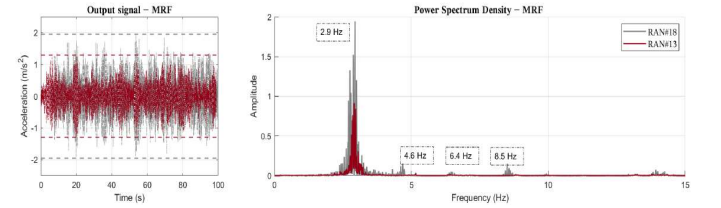
Level	Accelerometer	LVDT	Strain gauges
Floor 0	6	15	12
Floor 1	16	-	-
Floor 2	11	-	-
Floor 3	7	-	-
Roof top	14	4	-
Pipes (Pos. 1, 4, 5, 6)	-	12	12



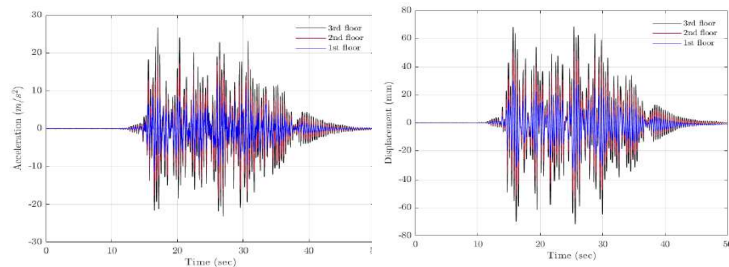
TEST PROGRAMME & MAIN OBSERVATIONS

Label	Excitation	State	Scaling factor	PGA Level	Observations
RND #13	Random	OBE - OP	-	0.05 g - 0.15 g	- Overall elastic linear behaviour
RND #15	Random	OBE - OP	-	0.05 g - 0.15 g	- Overall elastic linear behaviour
TH #8-25%	Seismic	OBE - OP	25%	0.16 g	- Overall elastic linear behaviour
TH #8-37%	Seismic	OBE - OP	37%	0.23 g	- Overall elastic linear behaviour
TH #8-50%	Seismic	OBE - DL	50%	0.31 g	- Overall elastic linear behaviour
RND #16	Random	OBE - OP	-	0.05 g - 0.15 g	- Overall elastic linear behaviour
TH #8-37%	Seismic	OBE - OP	37%	0.23 g	- 3 rd floor: collapse of pipe rack in the transversal direction
TH #8-70%	Seismic	OBE - DL	70%	0.44 g	- Large displ. (± 30 mm) of vertical Tank #2 at the 1 st floor
					- Relevant rotation of the cross beam under the vertical Tank #2 and warping of the web of fin plate D-FP #1
					- Strengthening of the cross-beam underneath Tank #2 in correspondence of D-FP #1
RND #17	Random	OBE - OP	-	0.05 g - 0.15 g	- Overall elastic linear behaviour
TH #8-37%	Seismic	OBE - OP	37%	0.23 g	- Overall elastic linear behaviour
TH #8-100%	Seismic	SSE - SD	100%	0.64 g	- D-FP #2,5,6 fin plate experienced cracking
TH #8-110%	Seismic	SSE - NC	110%	0.71 g	- Cracking on previously detail D-FP #2,5,6 significantly increased
					- Failure of bracing supporting the conveyor
RND #18	Random	OBE - OP	-	0.05 g - 0.15 g	- Overall elastic linear behaviour

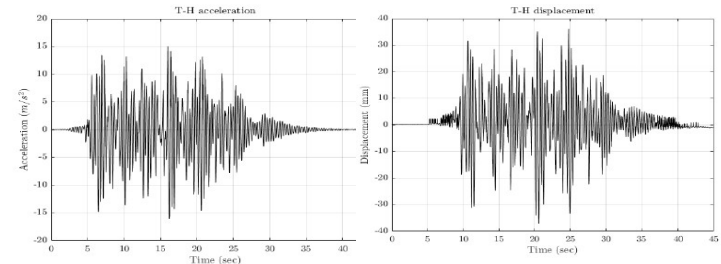
DYNAMIC IDENTIFICATION & MAIN RESULTS



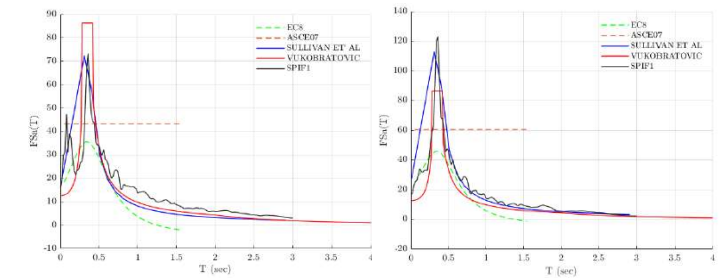
	MRF Direction				BF Direction			
	f_{n1} [Hz]	f_{n2} [Hz]	f_{n3} [Hz]	f_{n4} [Hz]	f_{n1} [Hz]	f_{n2} [Hz]	f_{n3} [Hz]	f_{n4} [Hz]
Random #13	2.91	5.20	6.33	8.73	5.21	7.12	-	14.48
Random #15	2.87	5.17	6.41	8.87	5.01	7.10	-	14.45
Random #16	2.88	5.13	6.36	8.82	4.94	7.13	-	14.38
Random #17	2.86	4.99	6.33	8.62	4.95	7.14	10.12	13.52
Random #18	2.84	4.68	6.38	8.57	4.75	6.38	9.69	13.30



Accelerations and displacements recorded at the three floor levels for the seismic record TH #8-110%



Time histories of both acceleration and relative displacement at the top of Tank #2 for the record TH #8-110%



Comparison of Analytical/Experimental floor response spectra for vertical tanks at the first floor

CONCLUSIONS & FUTHER DEVELOPMENTS

- EN-1998 and ASCE7 approach wrongly estimate the acceleration demand over a wide range of vibration periods, so more refined approaches for the prediction of floor response spectra are needed.
- The comprehensive testing campaign demonstrated a clear dynamic interaction between the primary steel structure and secondary process units that clearly influenced the performance of the whole system.
- The comparisons of the experimental results with a refined FE model will be object of further studies.
- Along this main vein, the efficiency of other steel configurations, e.g. the braced frame configuration, also in view of proper seismic retrofit interventions deserves further studies.



PUBLICATIONS

- Barbieri Vita L., Ciucci M., Marino A., Palermo O., Quinci G. "Valutazione e gestione del rischio sismico negli stabilimenti con pericolo di incidente rilevante." ANDIS 2019 Conference, September 15-19, 2019, Ascoli Piceno, Italy.
- Bursi O.S., Butenweg C., Lanese I., Marinkovic M., Nardin C., Paolacci F., Quinci G. "Seismic performance of an industrial plant substructure equipped with process components subject to shake table testing." Nuclear Engineering and Design journal.

MAIN REFERENCE

- Merino Vela R.J., Brunesi E., Nascimbene R. Derivation of floor acceleration spectra for an industrial liquid tank supporting structure with braced frame systems. *Engineering Structures*. vol. 171, pp. 105-122, 2018.
- Giannini R., Paolacci F., De Angelis M. Experimental investigation on the seismic response of a steel liquid storage tank equipped with floating roof by shaking table tests. *Earthquake Engineering Structural Dynamic* 2010; 39:
- Calvi P., Sullivan T.J. Estimating floor spectra in multiple degree of freedom systems. *Earthquake and Structures* 2014; 7: 17-38. doi: 10.12989/eas.2014.7.1.017.