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Application of impulse excitation technique to investigation of concrete damping and its changes at early ages

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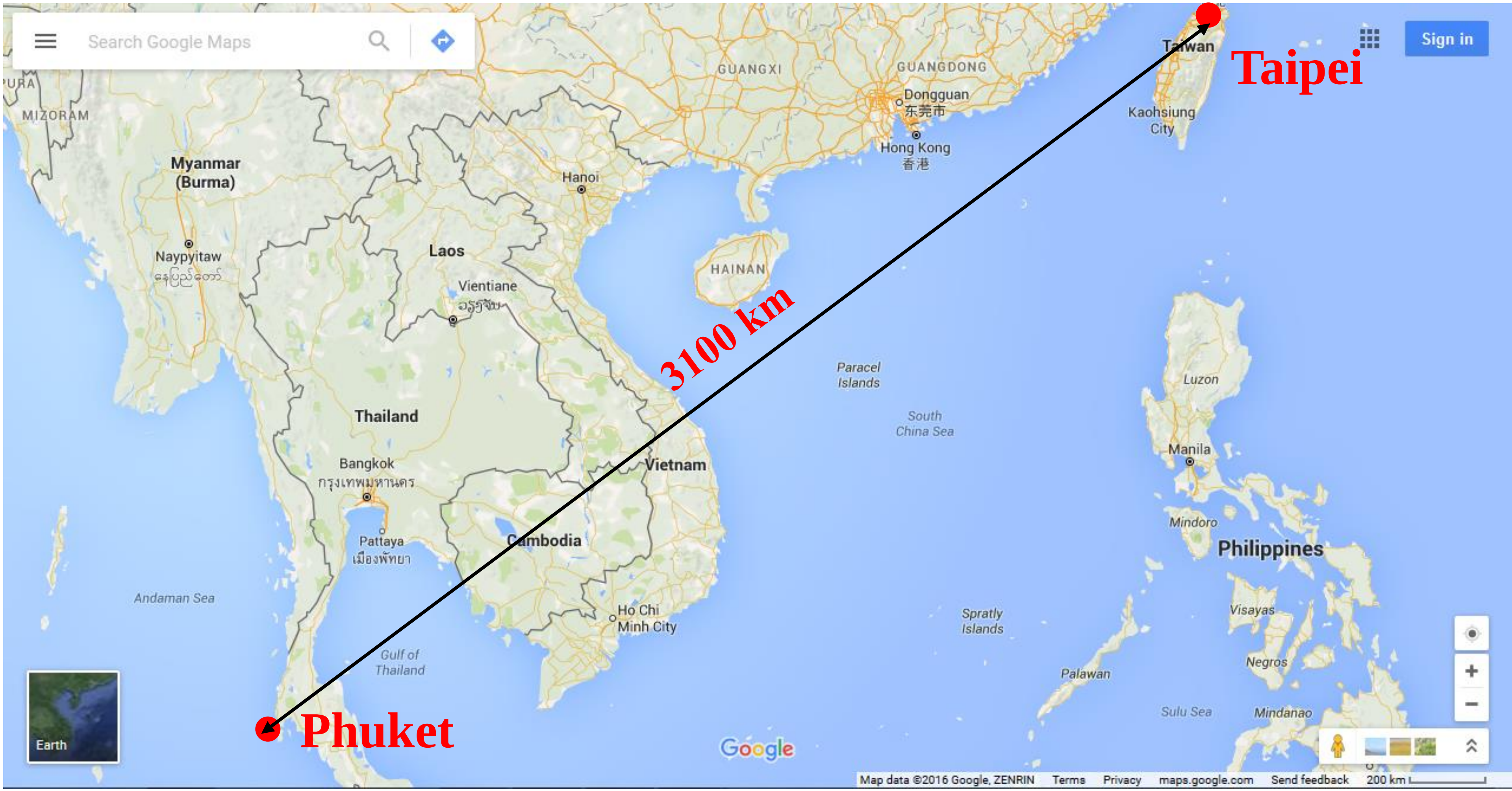


Statistic data of Taiwan Tech

#	Item	number	%
1	Undergraduate student	5500	55.0%
2	M.S. graduate student	3400	34.0%
3	Ph.D. graduate student	1100	11.0%
Total		10000	100%

- **2014-2015 Times Higher Education university ranking: 356**
- **2014/2015 QS (Quacquarelli Symonds) university ranking : 371**
- **2013 Times Higher Education-QS World University Rankings among Asian universities: 52**

Outline

- Abstract
- Introduction
- Impulse excitation technique
- Experimental setup
- Experiment and discussion
- Conclusions

Abstract (I)

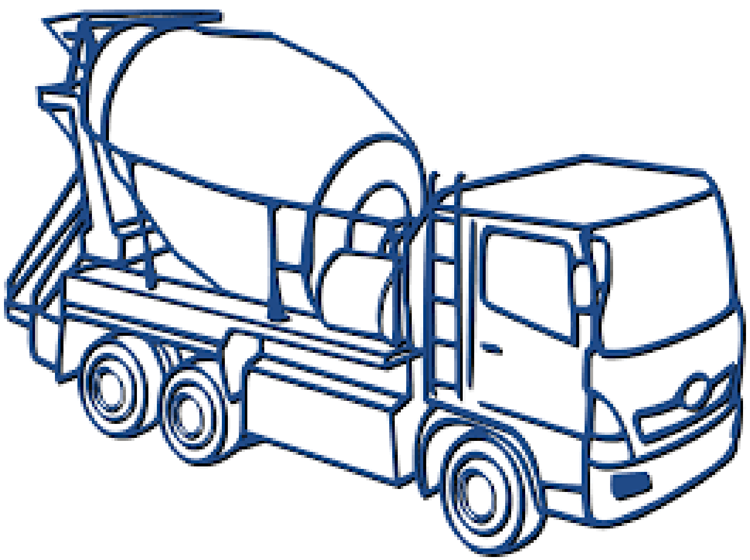
- This paper considers experimental results of internal friction test of concrete blocks using impulse excitation technique.
- Three concrete blocks (120 × 80 × 40mm) have been tested at the ages of 7, 14, 28, 56 and 91 days with the Resonant Frequency Damping Analyzer (RFDA) Basic.

Abstract (2)

- Mix proportions of the material were selected according to the ACI 211.1-91 method.
- The material of specimens is assumed to be isotropic, and it was proved that this assumption could be applied in practice.
- It was shown that damping of concrete reduces with time.

Abstract (3)

- The most significant changes occur at very early ages, before 14 days.
- After that this process slows down, however, it continues with a lower rate.



Introduction (I)

- Traditionally, concrete = purely elastic material, in reality, at early ages → not always.
- In fact, concrete is a viscoelastic material, especially at early ages.
- Fresh concrete is a viscous mixture of cement, water and aggregates in a basic composition.

Introduction (2)

- **Setting and hardening: elastic properties ↑ and viscous properties ↓**
- **Concrete transformation: viscoelastic material → elastic-like material**
- **Viscoelastic material: $E^*=E'+iE''$ - complex Yong's Modulus, where E' – elastic properties and E'' – viscous properties**

Introduction (3)

- Internal friction, or damping
- $Q^{-1} = E''/E'$
- is an important parameter to describe the properties and behavior of the material.

IET and RFDA

- Impulse excitation technique (IET)
- Light impact → vibrations → → microphone →Resonant Frequency and Damping Analyzer (RFDA) Software → Resonant Frequencies f_r →$Q^{-1} = k/\pi f_r$
- k - the exponential decay parameter
- Details [1,2]

Experimental setup (I)

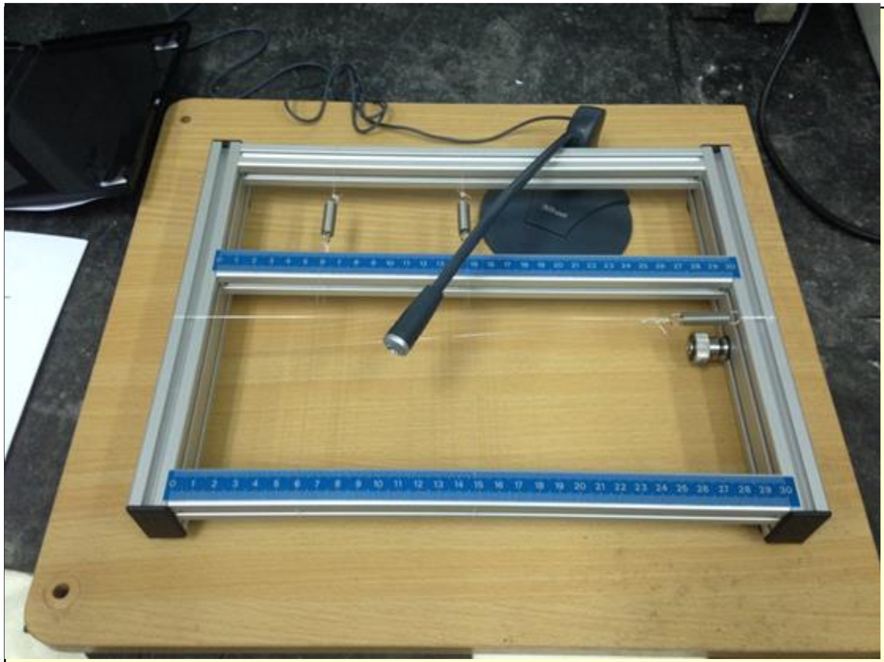


Fig. 1 Original universal wire support for the RFDA Basic

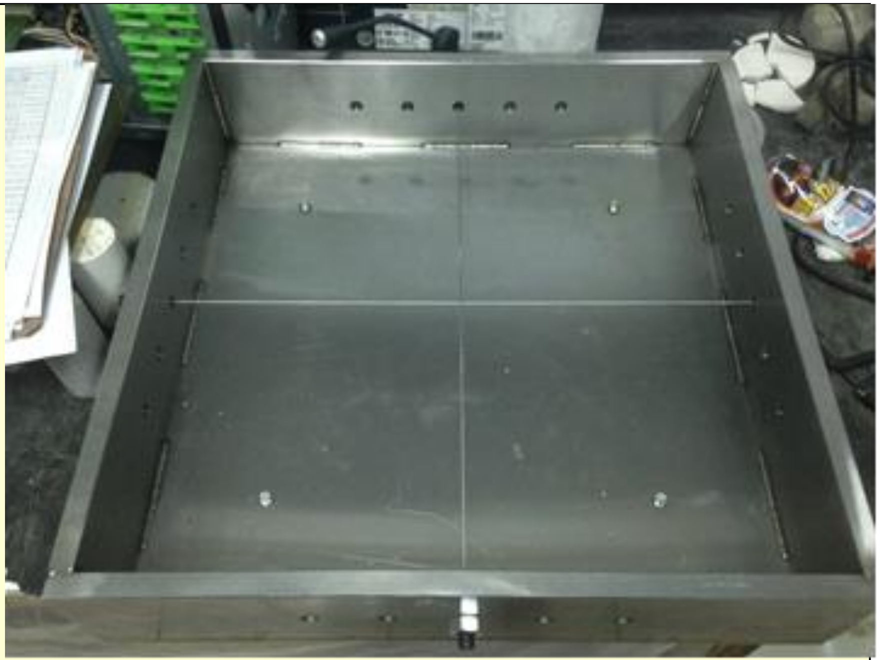


Fig. 2 Steel wire support designed by authors

RFDA software, USB hardware key, Logitech USB microphone, Universal wire support

Experimental setup (2)

Fig. 3 Damping test setup

Experimental setup (3)

Measurements result when the reference sample is impacted by the reference impactor using steel wire support

and

Measurements result when the reference sample is impacted by the steel spherical impactor (15.88 mm in diameter)

Are very close to each other =>

TYPE OF IMPACTOR DOESN'T AFFECT THE RESULTS

Experimental setup (4)

Tab. 1 Comparison of test results with different impactors

F, Hz	Loss rate	Damping	Peak value	F, Hz	Loss rate	Damping	E, GPa	G, GPa	v
8168.61	31.1	0.001211	168	10488.4	29.0	0.000880	209.42	80.55	0.3
8168.27	29.8	0.001159	126	10488.5	28.0	0.000849	209.40	80.55	0.3
8168.91	27.2	0.001058	172	10487.2	29.5	0.000895	209.44	80.53	0.3
8168.72	25.1	0.000977	222	10489.6	23.8	0.000721	209.42	80.57	0.3
8168.55	25.9	0.001009	173	10488.5	25.9	0.000787	209.41	80.55	0.3
8168.79	24.9	0.000969	202	10488.6	24.3	0.000736	209.43	80.55	0.3
8168.56	23.6	0.000919	154	10488.5	22.4	0.000681	209.41	80.55	0.3
8168.90	25.3	0.000985	270	10489.2	23.8	0.000723	209.43	80.56	0.3
8168.37	23.9	0.000931	99	10488.5	29.2	0.000886	209.40	80.55	0.3
8168.57	24.9	0.000969	144	10489.4	36.3	0.001103	209.41	80.56	0.3
8168.39	23.1	0.000899	211	10488.7	22.3	0.000676	209.40	80.55	0.3

F, Hz	Loss rate	Damping	Peak value	F, Hz	Loss rate	Damping	E, GPa	G, GPa	v
8168.4	23.6	0.000918	223	10489.2	24.9	0.000757	209.41	80.56	0.3
8168.8	21.4	0.000832	219	10488.7	33.1	0.001005	209.42	80.55	0.3
8170	27.2	0.00106	215	10488.6	26.4	0.000800	209.49	80.55	0.3
8169.1	21.3	0.000832	220	10487.7	28.9	0.000878	209.44	80.54	0.3
8169.5	20.6	0.000803	161	10487.9	22.2	0.000674	209.47	80.54	0.3
8169.5	22.9	0.000893	196	10489.6	26.1	0.000792	209.46	80.57	0.3
8169.8	25.6	0.000999	236	10489.4	28.6	0.000867	209.48	80.56	0.3
8170.4	24.3	0.000945	276	10491.1	24.9	0.000755	209.51	80.59	0.3
8170.9	22.6	0.000881	225	10490.5	29.7	0.000901	209.54	80.58	0.3
8170.1	24.7	0.000963	256	10490.7	26.6	0.000808	209.50	80.58	0.3

Experiment and discussion (I)

Fig. 4 Concrete blocks 120x80x40 mm for internal friction test

Experiment and discussion (2)

Tab. 2 Mix proportions, kg/m^3, ACI method

Water	Cement	Fine ag.	Coarse ag.	SP
213.849	484.751	796.384	881.462	2.200

Slump: 140 mm

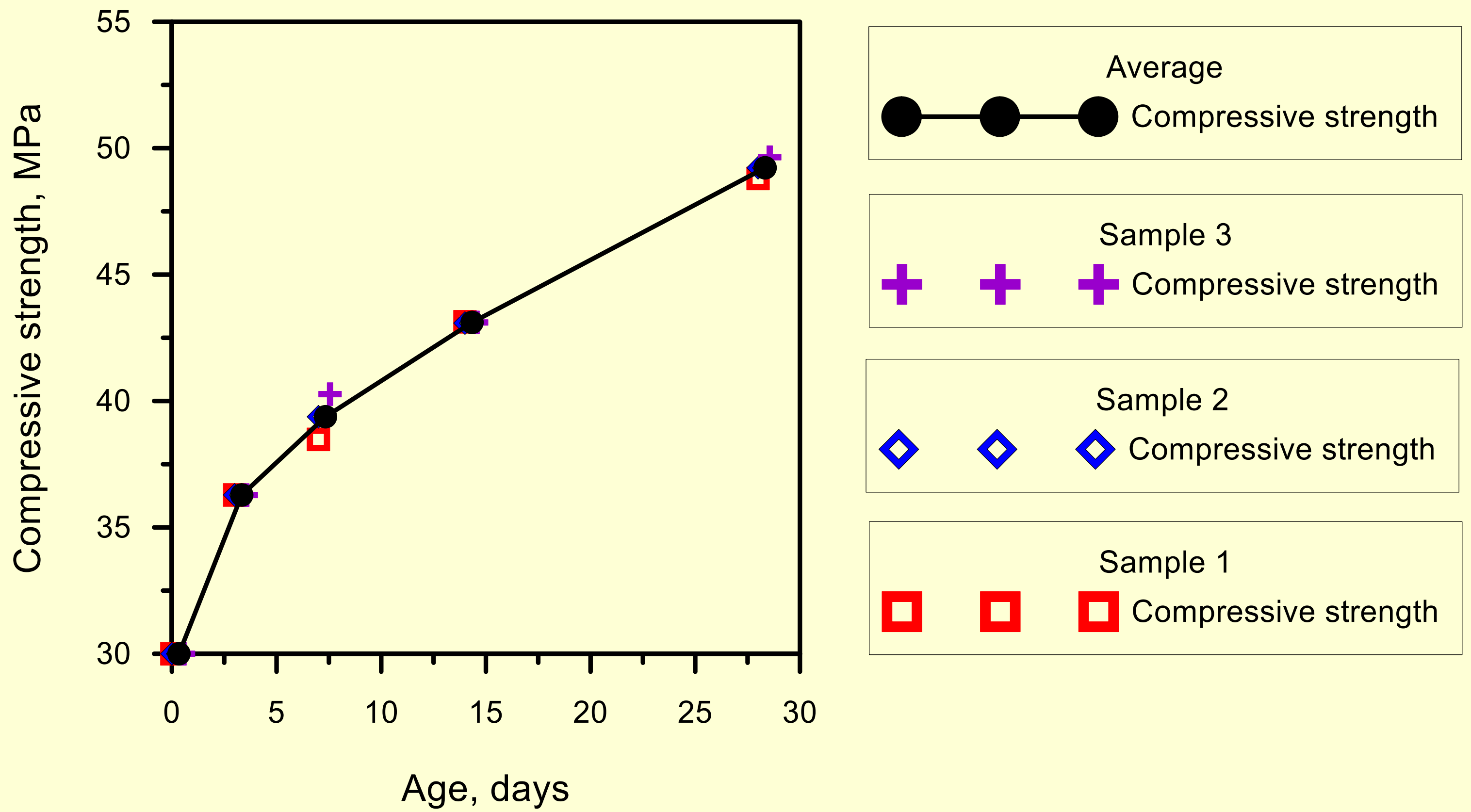
Curing conditions: wet

Experiment and discussion (3)

Fig. 5 Fresh concrete slump test: 140 mm

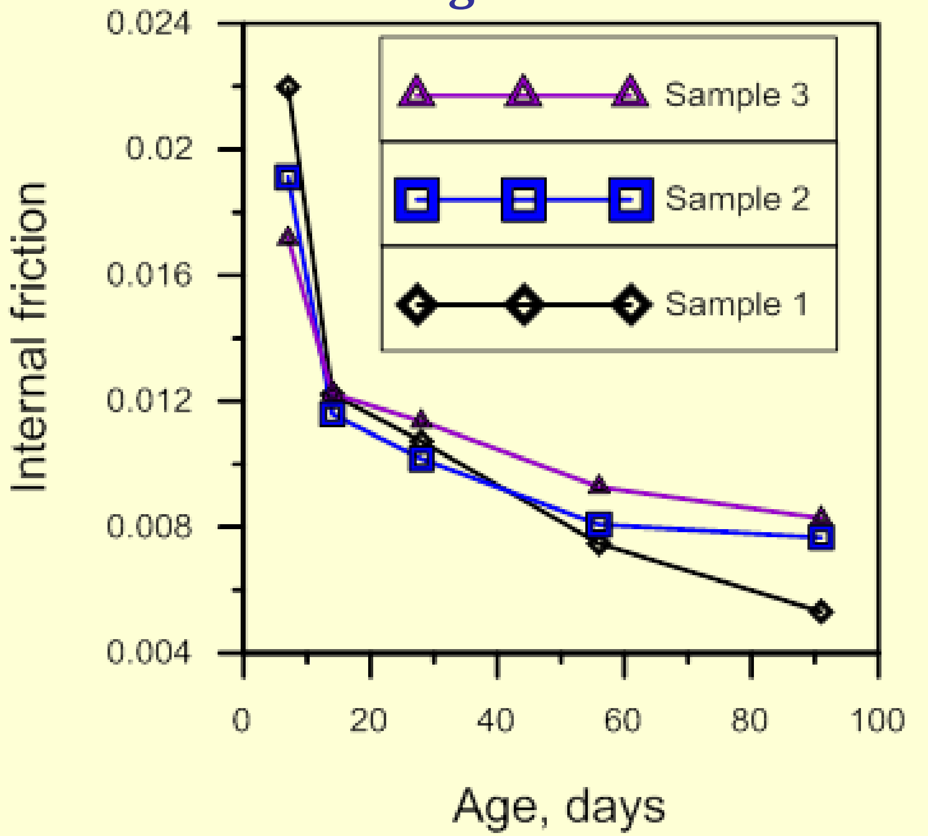
Experiment and discussion (4)

Fig. 5 Compressive strength development



Experiment and discussion (4)

Fig. 6 Internal friction (damping) changes with time



Isotropic material assumption

Similar to impact-echo method:

- The wavelengths of the stress waves are:
- 50mm ~ 2000mm
- longer than the scale of natural inhomogeneous regions in

concrete (aggregate, air bubbles, micro-cracks, etc.) [3].

Conclusions

- RFDA Basic → Concrete damping
- Assumption of isotropic material is OK!
- Damping: highest values at early ages
- Damping: decreases with time
- The most significant change: till 14 days
- After 14 days → slows down
- Hardening: E" %↓ within 2 weeks and E' %↑

Acknowledgement

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References

- [1] G. Roebben, B. Bollen, A. Brebels, J. Van Humbeeck and O. Van der Biest, Impulse excitation apparatus to measure resonant frequencies, elastic moduli, and internal friction at room and high temperature, Rev. Sci. Instrum. 68(12) (1997) 4511-4515.
- [2] IMCE RFDA Basic Manual v. 1.1, IMCE N.V., Slingerweg 52, B-3600 Genk, Belgium.
- [3] Field Instruments for Nondestructive Evaluation of Concrete & Masonry, Impact-Echo Instruments, LLC Ithaca, New York, 9 October, 2003, pp. 1-9.

Taipei 101 (height 509.2 m) World tallest building (Dec. 31, 2004 ~ Jan 4, 2010)

Thank you for your attention