

**IMPACT RESISTANCE OF FOAMED CONCRETE SLAB AND ITS
MODIFICATIONS SUBJECTED TO HEMISPHERICAL IMPACTOR**

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In the name of Allah, the most gracious and most merciful.
This thesis I dedicated for my beloved,

Fetra, my wife who always patient and gives me the support
Athhar and Fatharani my children who always give me support with
their happiness and cheerfulness

In memory, my beloved parent, RA. Siti Roniyun and Wignya Widjaya
My parent in law, Zamanhuri and Risnidar



PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

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ABSTRACT

This research work examined the interplay between three main methods: experimental works, analytical model and numerical simulation. The three methods employed slabs of foamed concrete and its modifications. The modifications of foamed concrete included foamed concrete substituting sand with Rice Husk Ash (RHA) and foamed concrete reinforced by Polypropylene fibre (PF). Experimental work produced properties data of density, compressive strength, tensile strength, modulus of elasticity and Poisson's ratio of slab specimens. The experiment of impact was conducted by using falling-weight impact tower method to get the depth of penetration data. The depth of crater as product of impact is called penetration depth. The basic properties of materials were used to run the numerical simulation and analytical model. The simulation applied the FE/DE method, whilst the analytical model was conducted by applying various theories and all its support from previous researchers both in empirical and non-empirical. The slab target subjected to hemispherical impactor with 7.7, 8.9 and 9.9 m/s impact velocity produced the crater without spalling or scabbing. This impact phenomenon was due to effect of porosity in matrix of foamed concrete and its modifications as foam material. Foamed concrete modifications were stronger than foamed concrete, which gave the shallower penetration depth than penetration depth of foamed concrete. Resistance of slab specimens subjected to impact loading can be predicted by its penetration depth. It can be determined by the assumption, when impactor hit the slab target, the diameter of impactor shank entirely into target due to porosity. The dimensional of penetration depth was derived when the impactor had kinetic energy and target initiate gave a reaction by its compressive strength against the force of impact. The dimensional penetration depth can be used as a formula to predict penetration depth of foamed concrete and its modification slabs subjected to hemispherical impact loading. The numerical simulation results were validated by the experimental results. Those three of analyses methods showed a tendency the same results for penetration depth.

ABSTRAK

Kajian ini dijalankan bagi mengkaji pengaruh antara tiga analisis utama: kerja-kerja kajian makmal, model analitik dan simulasi berangka. Perubahsuaian konkrit berbusa termasuklah konkrit berbusa dengan mengganti pasir dengan Abu Sekam Padi (RHA) dan konkrit berbusa diperkuat oleh Fiber Polipropelin (PF). Pengubahsuaian terhadap konkrit berbusa ini melibatkan tiga kaedah analisis. Kajian makmal menghasilkan sifat-sifat ketumpatan, kekuatan mampatan, kekuatan lenturan, modulus elastik dan nisbah Poisson konkrit berbusa dan pengubahsuaianya. Ujikaji hentaman dilakukan dengan menggunakan kaedah berat jatuhan menara hentaman untuk mendapatkan data kedalaman penembusan. Sifat-sifat asas bahan digunakan bagi menjalankan simulasi berangka and model analitik. Simulasi tersebut mengaplikasikan kaedah FE/DE bagi teknik analisis untuk simulasi hentaman. Model analitik dilakukan dengan menggunakan pendekatan analisis pelbagai teori dan kesemuanya disokong oleh penyelidikan-penyelidikan terdahulu sama ada empirical atau bukan empirical. Hentaman terhadap konkrit berbusa dan pengubahsuaian oleh penghentak hemisfera dengan kelajuan hentaman 7.7, 8.9 dan 9.9 m/s menghasilkan kawah tanpa 'spalling' atau 'scabbing'. Fenomena kesan hentaman disebabkan oleh keliangan konkrit berbusa. Perubahsuaian konkrit berbusa lebih kuat daripada konkrit berbusa dimana konkrit perubahsuaian mempunyai penembusan lebih dangkal daripada konkrit berbusa. Rintangan konkrit berbusa terhadap beban hentaman boleh diramalkan melalui penembusannya. Kedalaman kawah hasil hentaman dipanggil sebagai kedalaman penembusan. Ianya boleh ditentukan dengan anggapan apabila penghentak mengenai konkrit berbusa, keseluruhan diameter penghentak memasuki sasaran disebabkan oleh keliangan. Dimensi kedalaman penembusan diperolehi apabila penghentak mempunyai tenaga kinetik untuk menghentam sasaran dan konkrit berbusa memberi tindakbalas melalui kekuatan mampatannya bagi melawan daya yang dikenakan. Dimensi kedalaman penembusan boleh digunakan sebagai formula bagi meramalkan kedalaman penembusan konkrit berbusa dan pengubahsuaian oleh beban hentaman hemisfera. Hasil simulasi berangka disahkan oleh hasil kajian makmal. Ketiga kaedah analisis menunjukkan kecenderungan mendapat keputusan yang sama bagi kedalaman penembusan.

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REFERENCES

- ACE. (1946). *Fundamentals of Protective Structures, Report AT120 AT1207821, Army Corps of Engineers, Office of the Chief of Engineers.*
- Adeli, H., & Amin, A. M. (1985). Local effects of impactors on concrete structures. *Nuclear Engineering and Design, 88(3)*, 301-317.
- Al-Khalaf, M. N., & Yousif, H. A. (1984). Use of Rice Husk Ash in Concrete. *The International Journal of Cement Composites and Lightweight Concrete, 6*, 241-248.
- Aldridge, D. (2005). *Introduction To Foamed Concrete : What, Why, How?* Paper presented at the Used of Foamed Concrete in Construction, International Confrence of University of Dundee, Scotland UK.
- Aldrige, D., & Ansell, T. (2001). *Foam concrete: production and equipment design, properties, application and potential.* Paper presented at the In Proceedings one day seminar on foamed concrete: Properties, applications and latest technological developments, Loughborough University.
- Alhozaimy, A. M., Soroushian, P., & Mirza, F. (1996). Mechanical properties of polypropylene fiber reinforced concrete and the effects of pozzolanic materials. *Cement and Concrete Composites, 18(2)*, 85-92.
- Ali, M., Qamhiyah, A., Flugrad, D., & Shakoor, M. (2006). Compact Energy Absorbing Cellular Structure. *Structure Under Shock and Impact IX, 87*, 413-429.
- Amirikian, A. (1950). *Design of Protective Structures, Report NT-3276, The Americans Society of Civil Engineers. Bureau of Yards and Docks, Department of the Navy Washington, D.C.*
- Ando, T., Kishi, N., Mikami, H., & Matsuoka, K. G. (2000). Weight Falling Impact Tests On Shear-failure Type RC Beams Without Stirrups. *Structures Under Shock and Impact VI, 579-587.*
- ASTM-230. (1998). Specification for flow table for use in test of hydraulic cement.
- ASTM-C31/C-31M-00. (2000). Standard Practice for Making and Curing Concrete Test Specimens in Field. *04.02.*
- Backman, M. E., & Goldsmith, W. (1978). The mechanics of penetration of projectiles into targets. *International Journal of Engineering Science, 16(1)*, 1-99.
- Bangash, M. Y. H. (1989). Concrete and Concrete Structures: numerical modelling and application. *Elsevier Applied Science.*
- Banthia, N., & Gupta, R. (2006). Influence of polypropylene fiber geometry on plastic shrinkage cracking in concrete. *Cement and Concrete Research, 36(7)*, 1263-1267.
- Barr, P. (1990). Guidelines for the design and assessment of concrete structures subjected to impact. . *Report, UK Atomic Energy Authority, Safety and Reliability Directortae, HMSO, London.*

- Bazant, Z. P., & Kazemi, M. T. (1990). Determination of Fracture Energy, Process Zone Length and Brittleness number from Size Effect, With Application to Rock and Concrete. *International Journal of Fracture*, 44, 111-131.
- Bazant, Z. P., & Pfeiffer, P. A. (1987). Determination of Fracture Energy from Size Effect and Brittleness Number. *ACI Material Journal* 84(6), 463-480.
- Behnood, A., & Ghandehari, M. (2009). Comparison of compressive and splitting tensile strength of high-strength concrete with and without polypropylene fibers heated to high temperatures. *Fire Safety Journal*, 44(8), 1015-1022.
- Bentur, A., Mindess, S., & Vondran, G. (1989). Bonding in polypropylene fibre reinforced concretes. *International Journal of Cement Composites and Lightweight Concrete*, 11(3), 153-158.
- Beppu, M., Miwa, K., Itoh, M., Katayama, M., & Ohno, T. (2008). Damage evaluation of concrete plates by high-velocity impact. *International Journal of Impact Engineering*, 35(12), 1419-1426.
- Berriaud, C., Sokolovxky, A., Geuraud, R., Dulac, J., & Labrot, R. (1978). Local Behaviour of reinforced Concrete Walls Under Missile Impact. *Nuclear Engineering and Design*, 45, 457-469.
- Bischoff, P. H., & Perry, S. H. (1991). Compressive Behaviour of Concrete at High Strain Rates. *Materials and Structures* 24(6), 425-450.
- Booker, P. M., Cargile, J. D., Kistler, B. L., & La Saponara, V. (2009). Investigation on the response of segmented concrete targets to projectile impacts. *International Journal of Impact Engineering*, 36(7), 926-939.
- BS1881:Parts III. (1983). Testing Concrete. British Standards Institutions.
- BS-EN-12390-3:2009. (2009). Compressive Strength of Test Specimens.
- BS-EN-12390-6:2009. (2009). Testing Hardened Concrete Part 6: Tensile Splitting Strength of Test Specimens.
- BSEN-197-1. (2000). Cement —Part 1: Composition, specifications and conformity criteria for common cements.
- BSEN-450-1. (2005). Fly ash for concrete — Part 1: Definition, specifications and conformity criteria.
- BSEN-882. (1992). Specification for aggregates from natural sources for concrete.
- Bulson, P. S. (1997). Explosive Loading of Engineering Structures. London: E & FN Spon.
- Cantwell, W. J., & Morton, J. (1989). The influence of varying projectile mass on the impact response of CFRP. *Composite Structures*, 13(2), 101-114.
- Chang, W. S. (1981). Impact of Solid Missiles on Concrete Barriers. *J. Struct. Div. ASCE*, 107(ST2), 257-271.
- Chareerat, T., Pimraksa, K., Chindaprasirt, P., Maegawa, A., & Hatanaka, S. (2008). *Composition and Microstructure of Fly Ash Geopolymer Containing Rice Husk Ash*. Paper presented at the Technology and Innovation for Sustainable Development Conference (TISD2008), Faculty of Engineering, Khon Kaen University, Thailand.
- Chelapati, C. V., Kennedy, R. P., & Wall, I. B. (1972). Probabilistic assessment of aircraft hazard for nuclear power plants. *Nuclear Engineering and Design*, 19(2), 333-364.
- Chen, X. W., & Li, Q. M. (2002). Deep penetration of a non-deformable projectile with different geometrical characteristics. *International Journal of Impact Engineering*, 27(6), 619-637.

- D.R.J.Owen, Feng, Y. T., Jianguo, y., & Peric, D. (2001). Finite/Discrete Element Analysis of Multi-Fracture and Multi-Contact Phenomena. *VECPAR 2000, LNCS 1981*, 483-505.
- Dancygier, A. N., & Yankelevsky, D. Z. (1996). High strength concrete response to hard projectile impact. *International Journal of Impact Engineering*, 18(6), 583-599.
- ELFEN3.7.1. (2004). Rockfield Software Ltd., Swansea, UK.
- Frew, D. J., Forrestal, M. J., & Cargile, J. D. (2006). The effect of concrete target diameter on projectile deceleration and penetration depth. *International Journal of Impact Engineering*, 32(10), 1584-1594.
- Furlan Jr, S., & de Hanai, J. o. B. (1997). Shear behaviour of fiber reinforced concrete beams. *Cement and Concrete Composites*, 19(4), 359-366.
- Gibson, L. J., & Ashby, M. F. (1997). *Cellular Solids Structure and Properties* (second ed.): Cambridge University Press.
- Gwaltney, R. C. (1968). *Missile Generation and Protection in Light-Water-Cooled Power Reactor Plants* (No. ORNL-NSIC--22 United States Tue Feb 05 19:47:12 EST 2008 Dep. CFSTI. ORNL; NSA-22-050739 English).
- Haifeng, L., & Jianguo, N. (2009). Mechanical behavior of reinforced concrete subjected to impact loading. *Mechanics of Materials*, 41(12), 1298-1308.
- Haldar, A., & Hamieh, H. (1984). Local Effect of Solid Missiles on Concrete Structures. *ASCE J. Struct. Div.*, 110(5)(948-60).
- Hughes, G. (1984). Hard missile impact on reinforced concrete. *Nuclear Engineering and Design*, 77(1), 23-35.
- Hutchings, I. M. (1979). Energy Absorbed By Elastic Wave During Plastic Impact. *J. Phys. D*, 12, 1819-1824.
- Ismail, M. S., & Waliuddin, A. M. (1996). Effect of Rice Husk on High Strength Concrete. *Construction and Building Materials*, 10(7), 521-526.
- Jaini, Z. M., & Feng, Y. T. (2010). *Computational Modelling of Damage and Fracture Behaviour of Reinforced Slabs Subjected to Blast Loading*. Paper presented at the The first International Conference of Protective Structure
- Jensen, J. J. (1979). *Impact of falling loads on submerged structures*. Paper presented at the Proc. of Int. Symp. on Offshore Structure, Rio de Janeiro.
- Jensen, J. J., & Hoiseth, K. (1983). Impact of Dropped Objects on Lightweight Concrete. *Nordic Concrete Research*, 2, 102-113.
- Jones, M. R., & McCarthy, A. (2005). Preliminary views on the potential of foamed concrete as a structural material. *Mag Concr Res*, 57, 21-31.
- Jones, M. R., & McCarthy, A. (2006). Heat of hydration in foamed concrete: Effect of mix constituents and plastic density. *Cement and Concrete Research*, 36(6), 1032-1041.
- Jones, M. R., & Zheng, L. (2012). Energy Absorption of Foamed Concrete from Low-Velocity Impact. *ICE Publishing*, 65(4), 209-219.
- Jones, S. E., & Rule, W. K. (2000). On the optimal nose geometry for a rigid penetrator, including the effects of pressure-dependent friction. *International Journal of Impact Engineering*, 24(4), 403-415.
- Just, A., & Middendorf, B. (2009). Microstructure of high-strength foam concrete. *Materials Characterization*, 60(7), 741-748.
- Kakooei, S., Akil, H. M., Jamshidi, M., & Rouhi, J. (2012). The effects of polypropylene fibers on the properties of reinforced concrete structures. *Construction and Building Materials*, 27(1), 73-77.

- Karahan, O., & AtiÅÿ, C. D. (2010). The durability properties of polypropylene fiber reinforced fly ash concrete. *Materials & Design*, 32(2), 1044-1049.
- Kearsley, E. P. (1999). Just foamed concrete – an overview. In: Dhir R.K., Handerson NA, editors. Specialist techniques and materials for construction. London:Thomas Telford, pp. 227-237.
- Kearsley, E. P., & Mostert, H. F. (1997). Use of foamed concrete in South Africa. In: Proceedings from the ACI international conference on high performance concrete. sp 172-48. pp. 919-934.
- Kearsley, E. P., & Wainwright, P. J. (2001). The effect of high fly ash content on the compressive strength of foamed concrete. *Cement and Concrete Research*, 31(1), 105-112.
- Kearsley, E. P., & Wainwright, P. J. (2002). Ash content for optimum strength of foamed concrete. *Cement and Concrete Research*, 32(2), 241-246.
- Kearsley, E. P., & Wainwright, P. J. (2002). The effect of porosity on the strength of foamed concrete. *Cement and Concrete Research*, 32(2), 233-239.
- Kennedy, R. P. (1976). A review of procedures for the analysis and design of concrete structures to resist missile impact effects. *Nuclear Engineering and Design*, 37(2), 183-203.
- Klerck, P. A., Sellers, E. J., & Owen, D. R. J. (2004). Discrete fracture in quasi-brittle materials under compressive and tensile stress states. *Computer Methods in Applied Mechanics and Engineering*, 193(27â€“29), 3035-3056.
- Kojima, I. (1991). An experimental study on local behavior of reinforced concrete slabs to missile impact. *Nuclear Engineering and Design*, 130(2), 121-132.
- Lee, Y. L., & Hung, Y. T. (2005). *Exploitation of Solid Wastes in Foamed Concrete Challenges Ahead*. Paper presented at the Use of Foamed Concrete in Construction, International Confrence of University of Dundee, Scotland, UK Thomas Relford.
- Leppänen, J. (2006). Concrete subjected to projectile and fragment impacts: Modelling of crack softening and strain rate dependency in tension. *International Journal of Impact Engineering*, 32(11), 1828-1841.
- Li, Q. M., & Chen, X. W. (2003). Dimensionless formulae for penetration depth of concrete target impacted by a non-deformable projectile. *International Journal of Impact Engineering*, 28(1), 93-116.
- Li, Q. M., Reid, S. R., & Ahmad-Zaidi, A. M. (2006). Critical impact energies for scabbing and perforation of concrete target. *Nuclear Engineering and Design*, 236(11), 1140-1148.
- Li, Q. M., Reid, S. R., Wen, H. M., & Telford, A. R. (2005). Local impact effects of hard missiles on concrete targets. *International Journal of Impact Engineering*, 32(1-4), 224-284.
- Li, Y.-X., Chen, Y.-M., Wei, J.-X., He, X.-Y., Zhang, H.-T., & Zhang, W.-S. (2006). A study on the relationship between porosity of the cement paste with mineral additives and compressive strength of mortar based on this paste. *Cement and Concrete Research*, 36(9), 1740-1743.
- Liew, A. C. M. (2005). *New Innovative Lightweight Foam Concrete Technology*. Paper presented at the Proceeding of the International Conference: Use of Foamed Concrete in Construction, University of Dundee, Scotland, UK.
- Lo, T. Y., & Cui, H. Z. (2004). Effect of porous lightweight aggregate on strength of concrete. *Materials Letters*, 58(6), 916-919.
- Lo, T. Y., Tang, W. C., & Cui, H. Z. (2007). The effects of aggregate properties on lightweight concrete. *Building and Environment*, 42(8), 3025-3029.

- Lu, G. a. Y., T. (2003). *Energy Absorption of Structures and Materials*. Abington Cambridge, England: Woodhead Publishing Limited.
- May, I. M., Chen, Y., D.R.J.Owen, Feng, Y. T., & Bere, A. T. (2005). *Experimental Testing and Finite Element Simulation of the Behaviour of Reinforced Concrete Beams Under Impact Loading*. Paper presented at the VIII International Conference on Computational Plasticity COMPLAS VIII, Barcelona.
- Mujahid, A. Z. A., & Li, Q. M. (2009). Investigation on Penetrating Resistance of Foamed Concrete. *Structure and Building*, 162, 77-85.
- Nambiar, E. K. K., & Ramamurthy, K. (2006a). Influence of filler type on the properties of foam concrete. *Cement and Concrete Composites*, 28(5), 475-480.
- Nambiar, E. K. K., & Ramamurthy, K. (2006b). Models relating mixture composition to the density and strength of foam concrete using response surface methodology. *Cement and Concrete Composites*, 28(9), 752-760.
- Nambiar, E. K. K., & Ramamurthy, K. (2007). Sorption characteristics of foam concrete. *Cement and Concrete Research*, 37(9), 1341-1347.
- Narayanan, N., & Ramamurthy, K. (2000). Structure and Properties of Aerated Concrete: A Review. *Cement and Concrete Composites*, 22, 321-329.
- NDRC. (1946). *Effect of impact and Explosion. Summary Technical Report of Division 2, vol.1, National Defence Research Committee, Washington, DC*.
- Newman, J., & Owens, P. (2003). Properties of lightweight concrete. In *Advanced Concrete Technology Set* (pp. 3-29). Oxford: Butterworth-Heinemann.
- Nili, M., & Afroughsabet, V. (2009). The effects of silica fume and polypropylene fibers on the impact resistance and mechanical properties of concrete. *Construction and Building Materials*, 24(6), 927-933.
- Odler, I. (2000). *Special Inorganic Cement* (Vol. 8). New York: E & FN Spon.
- Oh, B.-H., Jang, S.-Y., & Hyum-Kyun, B. (1999). Prediction of Fracture Energy of Concrete. *KCI Concrete Journal* 11(3), 211-221.
- Papayianni, I., & Milud, I. A. (2005). *Production of Foamed Concrete With High Calcium Fly Ash*. Paper presented at the Used of Foamed Concrete in Construction, University of Dundee, Scotland UK.
- Park, S. W., Xia, Q., & Zhou, M. (2001). Dynamic behavior of concrete at high strain rates and pressures: II. numerical simulation. *International Journal of Impact Engineering*, 25(9), 887-910.
- Pine, R. J., Coggan, J. S., Flynn, Z. N., & Elmo, D. (2006). The Development of New Numerical Modeling Approach for Naturally Fractured Rock Masses *Rock Mechanics and Rock Engineering*, 39(5), 395-419.
- Piqué, E. J. (2002). *Fracture process zone of quasi brittle materials: a model material approach*. Technische Universiteit Eindhoven., Eindhoven.
- Ramamurthy, K., Nambiar, E. K., & Indu Siva Ranjani, G. (2009). A classification of studies on properties of foam concrete. *Cement and Concrete Composites*, 31(6), 388-396.
- Ramezaniapour, A. A., Mahdi Khani, M., & Ahmadibeni, G. (2009). The effect of Rice Husk Ash on Mechanical Properties and Durability of Sustainable Concretes. *International Journal of Civil Engineering*, 7, 83-91.
- Raphael, J. M. (1984). Tensile Strength of Concrete. *Journal of the American Concrete Institute*, 158-165.
- Riera, J. D. (1989). Penetration, scabbing and perforation of concrete structures hit by solid missiles. *Nuclear Engineering and Design*, 115(1), 121-131.

- Riera, J. D., & Iturrioz, I. (1998). Discrete elements model for evaluating impact and impulsive response of reinforced concrete plates and shells subjected to impulsive loading. *Nuclear Engineering and Design*, 179(2), 135-144.
- Rodríguez de Sensale, G. (2006). Strength development of concrete with rice-husk ash. *Cement and Concrete Composites*, 28(2), 158-160.
- Serrano-Perez, J. C., Vaidya, U. K., & Uddin, N. (2007). Low velocity impact response of autoclaved aerated concrete/CFRP sandwich plates. *Composite Structures*, 80(4), 621-630.
- Shiu, W., Donzé, F. V., & Daudeville, L. (2008). Penetration prediction of missiles with different nose shapes by the discrete element numerical approach. *Computers & Structures*, 86(21-22), 2079-2086.
- Sliter, G. E. (1980). Assessment of Empirical Concrete Impact Formulas. *ASCE J. Struct. Div.*, 106 (ST5), 1023-1045.
- Sukhla, A., Tekalur, S. A., Gardner, N., Jackson, M., & wang, E. (2009). Performance of Novel Composites and Sandwich Structures Under Blast Loading. In *Major Accomplishments in Composite Materials and Sandwich Structures* (pp. 503-540): Springer Netherlands.
- Sun, Z., & Xu, Q. (2009). Microscopic, physical and mechanical analysis of polypropylene fiber reinforced concrete. *Materials Science and Engineering: A*, 527(1-2), 198-204.
- Tedesco, J. W., Powell, J. C., Ross, C. A., & Hughes, M. L. (1997). A strain-rate-dependent concrete material model for ADINA. *Computers & Structures*, 64(5-6), 1053-1067.
- Teng, T.-L., Chu, Y.-A., Chang, F.-A., & Chin, H.-S. (2004). Simulation model of impact on reinforced concrete. *Cement and Concrete Research*, 34(11), 2067-2077.
- Tipler, P. A. (Ed.). (1991). *Physics for Scientist and Engineering* (third ed. Vol. 1): Worth Publisher, Inc.
- Toyota, K., Okubo, K., Fujii, T., Oguri, T., & Uenoya, T. (2006). Mechanical Properties of Plain-Woven CFRP Reinforced by Spread Fiber Tow During and After Drop-Weight Impact. *Structures Under Shock and Impact IX*, 455-463.
- Whiffen, P. (1943). UK Road Research Laboratory Note No. MOS/311.
- Wu, C.-Y., Li, L.-Y., & Thornton, C. (2005). Energy dissipation during normal impact of elastic and elastic-plastic spheres. *International Journal of Impact Engineering*, 32(4), 593-604.
- Yankelevsky, D. Z. (1997). Local response of concrete slabs to low velocity missile impact. *International Journal of Impact Engineering*, 19(4), 331-343.
- Yankelevsky, D. Z., & Avnon, I. (1998). Autoclaved aerated concrete behavior under explosive action. *Construction and Building Materials*, 12(6-7), 359-364.
- Zhang, M. H., Lastra, R., & Malhotra, V. M. (1996). Rice-husk ash paste and concrete: Some aspects of hydration and the microstructure of the interfacial zone between the aggregate and paste. *Cement and Concrete Research*, 26(6), 963-977.
- Zhang, M. H., Shim, V. P. W., Lu, G., & Chew, C. W. (2005). Resistance of high-strength concrete to projectile impact. *International Journal of Impact Engineering*, 31(7), 825-841.
- Zielinski, A. J. (1984). *Concrete Structures under impact loading Rates effect*. Stevinweg 4: Delft University of Technology Department of Civil Engineering.