Thesis title

Strain rate dependent plasticity-based damage model for predicting the behaviour of concrete under dynamic loads

Overview:

To develop the pressure and strain rate dependent plasticity-based damage model for concrete. The proposed rate-sensitive damage model is able to incorporate the key experimental evidence on the effects of strain rate and damage rate. With increasing strain rates, the model is able to capture the decrease in the rate of damage evolution due to artificial stiffening effects, and the final level of damage is higher. The model has four parts, the incremental effective stress-strain relationships are defined in terms of rate of damage, accumulated damage and viscosity parameters reflecting the inherent physical inertial, thermal and viscous mechanisms respectively. The stress-strain relationship also accounts for stress reversals that occur due to interference of an incident and reflected wave, by including a Heaviside function. The equation of state gives the pressure versus volumetric strain relationship. The failure surface is enhanced by the strain rate experienced by the material and is provided with the limiting value rather than assuming that the strength of the material increases indefinitely. Along with the tension and compression damage, hydrostatic damage is considered. Verification, validation and parameterization of the developed model have been made through several numerical analyses. The application of the model is done for the structural characterization of reinforced cement concrete (RCC) slabs subjected to blast, impact and combined dynamic loading.

Objectives:

The objective of the current study is to predict the key experimental evidence on the effects of strain rate and damage rate on the material.

- To propose a strain rate-dependent plasticity-based model for predicting damage in concrete under dynamic loading.
- To propose a modification to the above model to include the effect of strain rate, pressure and damage rate to the plasticity-based damage model for predicting the behaviour of concrete under dynamic loading.
- The model will include a constitutive relation to account for the tension and compressive stress state, damage rate and viscosity behaviour of the material, the pressure versus volumetric strain relationship and failure surface.
  - (i) To develop a UMAT subroutine in LS-DYNA for this purpose.
  - (ii) To carry out the material calibration and validation of the proposed model using compression, tension and Split Hopkinson Pressure Bar (SHPB) analysis.
  - (iii) To apply the developed model to predict the behaviour of RCC slabs under combined dynamic loads of blast and impact analysis.

(iv) To perform a detailed parametric study by considering a) Sequence of loading b)Scaled distance c) Reinforcement ratio d) Velocity of Impact load e) Concrete strength

The scope of the current study is defined below.

- The scope of the developed model is limited to constant dynamic Young's modulus value with increasing strain rate.
- The parameters of the developed model is given only for 40 MPa concrete.
- There are many parameters in the developed model but there is no unique way to determine the input parameters.

Research Interest

Strain rate dependent damage model, Plasticity based damage model, Damage Mechanics, Dynamic behavior of concrete, High strain rate, Blast and Impact loading, Split Hopkinson Pressure Bar, Shock tube

Talks

1) Indo-Japan Workshop on India Japan Workshop on Computational Modeling of Damage and Seismic vulnerability assessment during Earthquakes in Building systems conducted in IITH. Presented on the topic Plasticity based damage model for predicting damage in concrete under dynamic loading.

Publications

Journal

1) K.A.Gomathi, A.Rajagopal, K.S.S.Reddy, and B.Ramakrishnan. Plasticity based material model for concrete subjected to dynamic loadings. International Journal of Impact Engineering, 142:103581, 2020. https://doi.org/10.1016/j.ijimpeng.2020.103581.
2) K.A.Gomathi, A.Rajagopal, Dynamic Performance of Reinforced Concrete Slabs under Impact and Blast Loading using Plasticity-Based Approach. International Journal of Structural Stability and Dynamics, 20, 14, 2043015, 2020. https://doi.org/10.1142/S0219455420430154.
3) K.A.Gomathi, A.Rajagopal, K.S.S.Reddy, and B.Ramakrishnan. Plasticity based material model for concrete subjected to dynamic loadings. International Journal of Impact Engineering, 142:103581, 2020. (Impact factor-4.592).
4) Rajkumar D, R Senthil, B.Bala Murali Kumar, K.A.Gomathi, S.Mahesh Velan. Numerical study on parametric analysis of reinforced concrete column under blast loading. Journal of performance of constructed facilities, 34(1):04019102, 2020. (Impact factor-2.37)

5) K.A.Gomathi, K.S.S.Reddy, A.Rajagopal, K.V.L.Subramaniam, T.Rabczuk, Rate-sensitive plasticity based damage model for concrete under dynamic loading, (Submitted to IJIE)
6) K.A.Gomathi, A.Rajagopal, K.V.L.Subramaniam, T.Rabczuk, Application of Rate-sensitive plasticity based damage model subjected to near and contact explosion, (Submitted to MAMD)
7) L.Akhil, K.A.Gomathi, R.Jayaram, W.Paul, A.Rajagopal, Predicting the material characteristics of concrete using the shock tube analysis, (Under preparation)

Book chapter

1) K.A.Gomathi, A.Rajagopal, Numerical Damage Modelling of RC Slabs Under Blast Loading Using K&C Concrete Model, Recent Advances in Computational Mechanics and Simulations, 103, 529- 541, 2020. https://doi.org/10.1007/978-981-15-8138-0_40.
2) K.A.Gomathi, A.Rajagopal, Impact analysis of concrete structure using rate-dependent damage model, Composite Materials: High Strain Rate Studies.

Conference Proceedings

1) K.A. Gomathi, A. Rajagopal, Damage Evolution and Pressure Dependent Plasticity Model for Concrete under Dynamic Loading, Springer Nature's Proceedings series: Advances in Structural Integrity for Mechanical, Civil, and Aerospace Applications: Proceedings of SICE 2022, Volume 1.

Conference

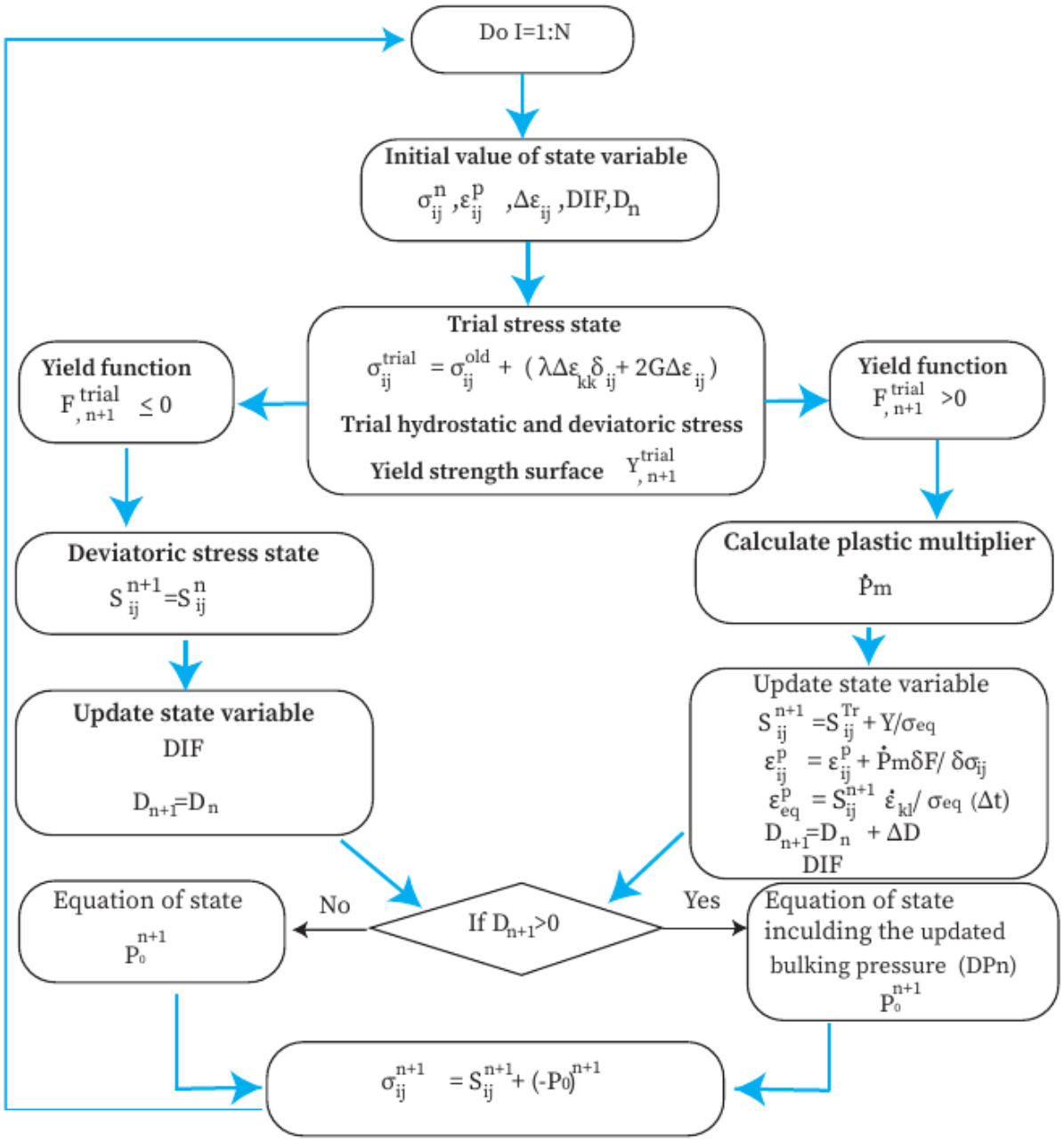
1) K.A.Gomathi, A.Rajagopal, Numerical damage modelling of RC slabs under blast loading using K&C concrete model, 7th International Congress on Computational Mechanics and Simulation, Paper ID-ICCMS19SD105139, IIT Mandi, India, 2019.
2) K.A.Gomathi, A.Rajagopal, Dynamic performance of RC slab under blast and impact loading, 3rd Structural Integrity Conference and Exhibition (SICE 2020 e-Conference), India, 2020.
3) K.A.Gomathi, A.Rajagopal, Numerical dynamic response of RC slabs subjected to combined blast and impact loading using plasticity based material model, 7th International Conference on Mechanics of Composites, Faculty of Engineering, University of Porto, Portugal, 2021.
4) K.A.Gomathi, A.Rajagopal, Impact analysis of concrete structure using rate dependent damage model, IIT Madras, Implast 2022, The 13th International Symposium on plasticity and impact mechanics, 2022.
5) K.A.Gomathi, A.Rajagopal, Damage evolution and pressure dependent plasticity model for concrete under blast loading, IITH, SICE, 2022. (To be presented)

Paper Presentation

1) K.A.Gomathi, A.Rajagopal, Proposing damage model for concrete by considering the limitation of the in-built model of LS-DYNA, Computational methods in sciences and engineering (CMSE-2022), BITS-Pilani, Hyderabad, India.

Relevant diagrams, flowcharts and results

Flow chart showing UMAT implementation of the plasticity-based model in LS-DYNA.



Application of proposed model for analysis of RCC slabs under the blast, impact and combined impact and blast loading

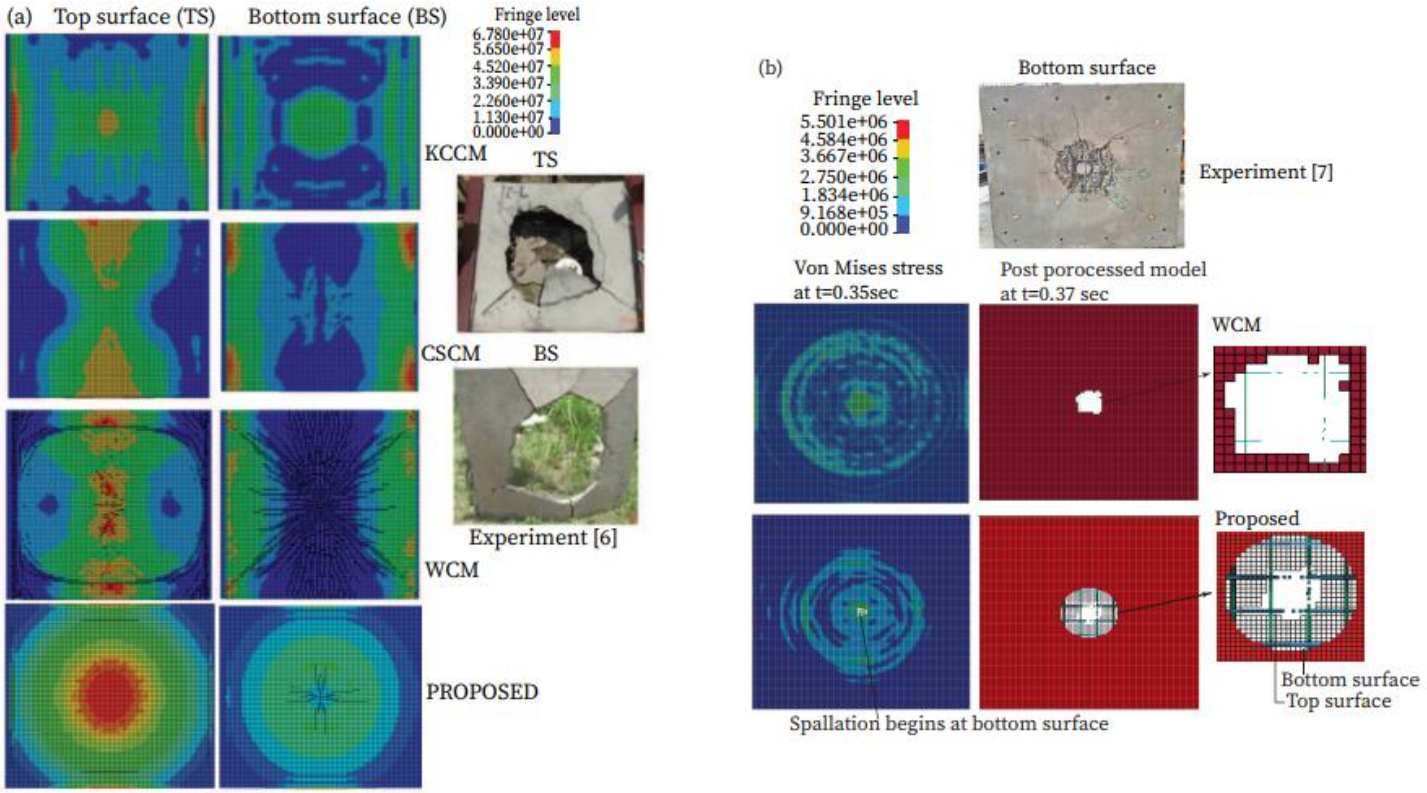


Fig: (a) Comparison of Von Mises stress fringes component at maximum central deflection with experiment for a reinforcement spacing of 700mm and 0.13kg TNT explosive (b) Comparison of Von Mises stress fringes component at time t=0.35s and post processed damage plot at t=0.37s for a 75mm reinforcement spacing under impact loading (Bottom surface).

Rate sensitive damage model

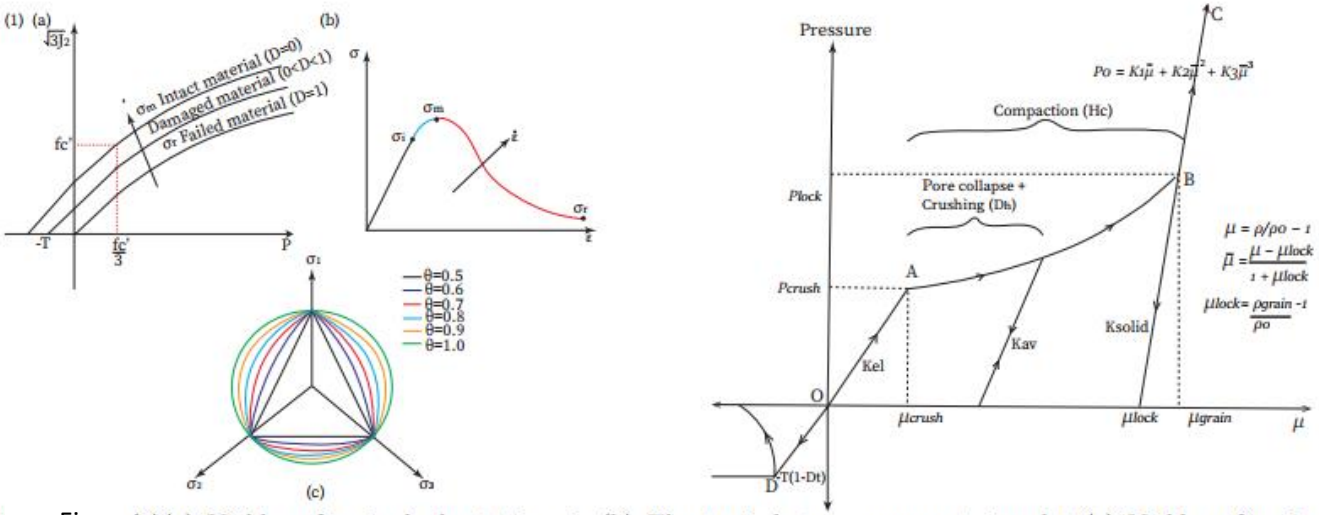


Fig: (1)(a) Yield surface in hydrostatic axis (b) The typical stress versus strain plot (c) Yield surface in deviatoric axis (2) Pressure versus volumetric strain relationship.

Parametrization and validation of developed model

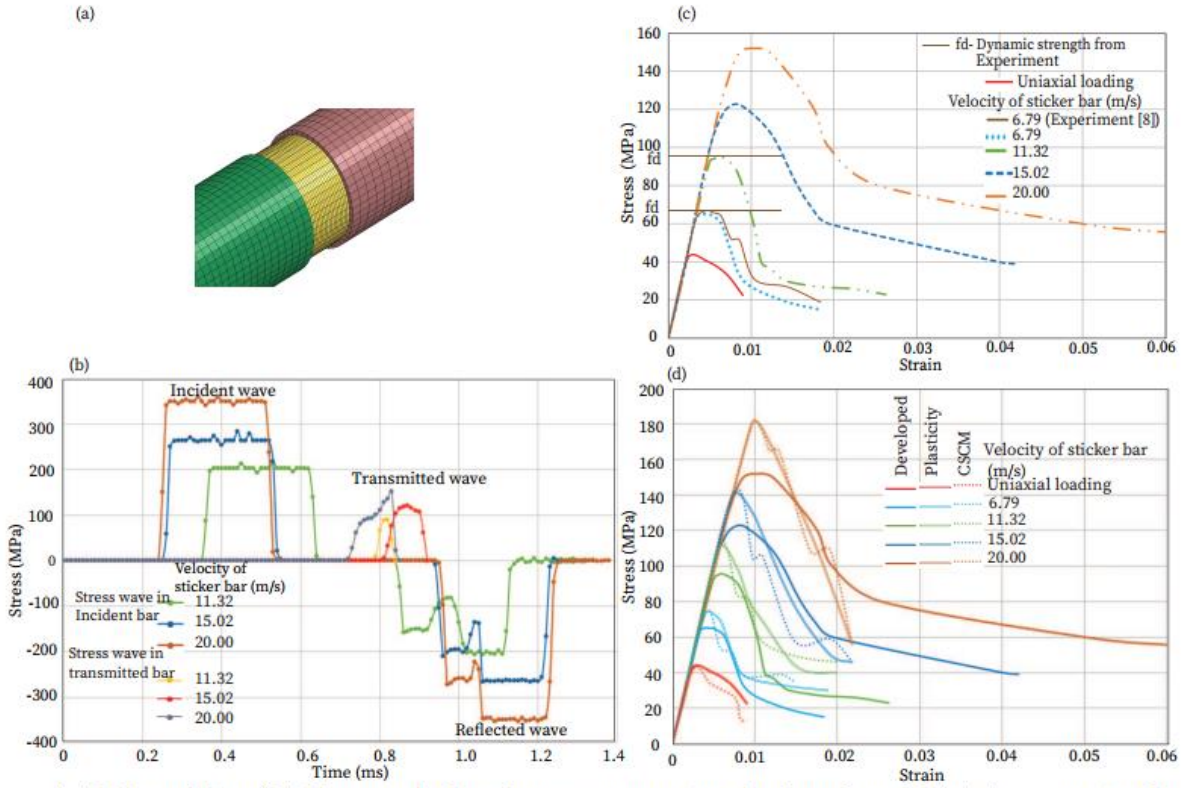


Fig: (a) FE modeling (b) Numerical plot of stress wave using developed model (c) Stress-strain plot when sticker bar is subjected to different incident velocity using developed model (d)compared with plasticity and CSCM model.

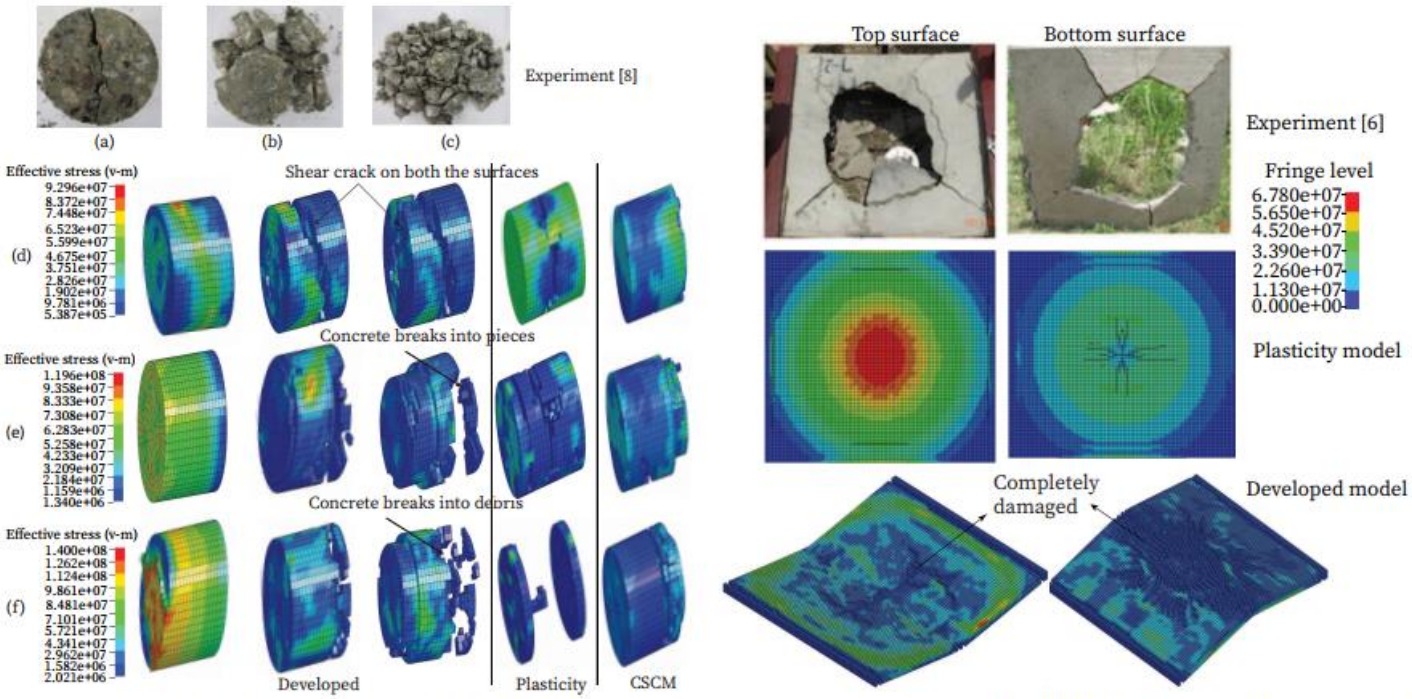


Fig: (1) Effective stress to understand the damage mechanism of concrete under SHPB analysis- Experimental results when sticker bar is given different incident velocity (a),(d) 11.32m/s (b),(e) 15.02m/s (d),(f) 20 m/s. (2) Comparison of stress plot to understand the damage mechanism of the plasticity and developed model to that of experimental results for 700mm reinforcement spacing.