UNIVERSITY OF TOKYO

Simulation of Concrete Cracking Pattern Combining DEF and ASR Expansion

by

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A thesis submitted in partial fulfillment for the degree of
Master

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Department of Civil Engineering

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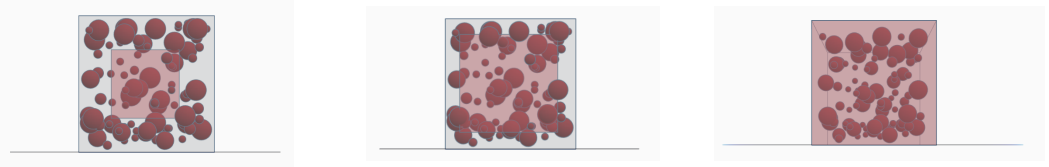
0.0.1 Expansion Intensified Part Range Related to Behavior of Concrete During DEF Expansion



(A) Intensified 50x50x50mm Case Cross Section (B) Intensified 75x75x75mm Case Cross Section (C) Intensified 100x100x100mm Case Cross Section

FIGURE 1: DEF intensified part range

In this section, DEF expansion simulation result of intensified center 75x75x75mm and uniformly expansion for all part (intensified center 100x100x100mm) is presented.

0.0.1.1 Expansion Intensified 75x75x75mm at Center of Model

Initial Strain (Each Step)	Expanding Steps	Final Expansion[%]
0	0	0
0.001	20	0.1671
0.002	20	0.3380
0.003	20	0.5118
0.005	20	0.8577

TABLE 1: One Dimensional Expansion Ratio in Expansion Intensified 75x75x75mm at Center of Model DEF Model Simulation

0.0.1.2 Expansion Intensified 100x100X100mm at Center of Model

Initial Strain (Each Step)	Expanding Steps	Final Expansion[%]
0	0	0
0.001	20	0.2
0.002	20	0.4087
0.004	20	0.6191
0.006	20	1.0454

TABLE 2: One Dimensional Expansion Ratio in Expansion Intensified 100x100X100mm at Center of Model DEF Model Simulation

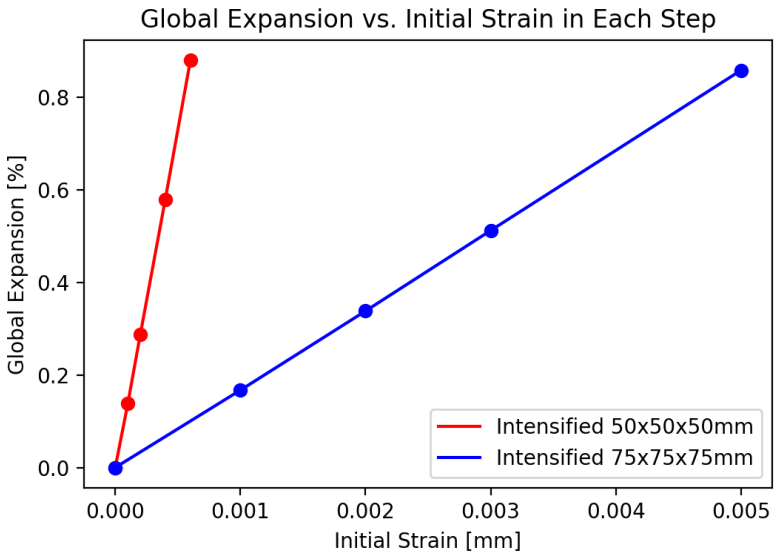


FIGURE 2: Global Expansion vs. Step

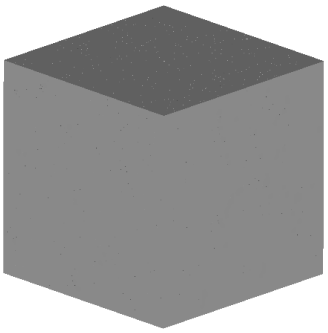
From Figure **??**, Figure 4, Figure **??** and Figure 8, it can be seen that when intensified the DEF expansion at the center 75x75x75mm, still the characteristic map cracking pattern can be achieved, which is similar to 50x50x50mm case.

However, when comparing to uniformed overall expansion (DEF expansion at the center 75x75x75mm), the increasing of the concrete volume is achieved without generating significant surface cracks. This simulation result is correlated with the research result done by L.Eddy et.al., 2016, concluded as the simply uniformed paste expansion does not present DEF simulation well as it behaves in reality.

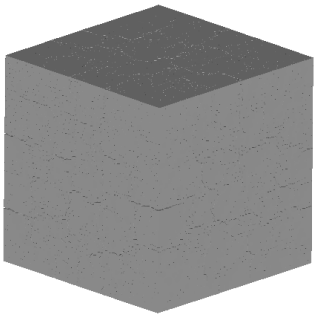
When examined closely of the intersection, it can be seen that no inner crack is happening in the paste for the uniformed expanding case, separation only happens between the surface of aggregate and paste, which is different with other 2 cases.

With expansion intensified in the inner part of concrete model, the compressive force concentrated in the inner part of the model, while outer parts are under tension. This unbalanced force generates cracks at the surrounding part of the concrete, preset as map cracking pattern at the surface view. This cracking pattern is also correlated with the observation form A.Awasthi in his investigation of DEF deteriorated Indian concrete sleeper in 2016.

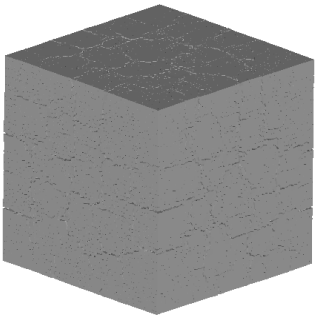
Figure here.



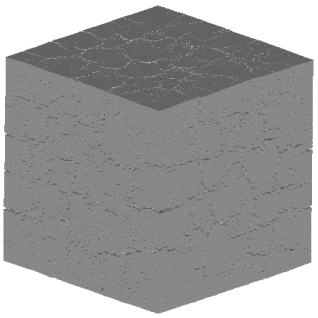
(A) Case 0: 0% Expansion



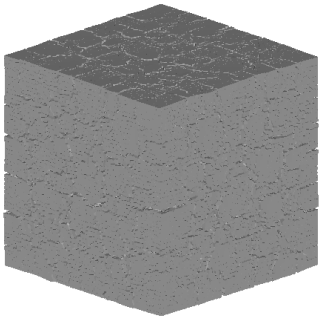
(B) Case 1: 0.1671% Expansion



(C) Case 2: 0.3380% Expansion

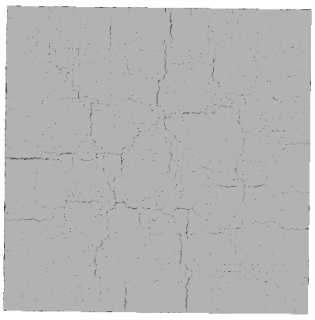


(D) Case 3: 0.5118% Expansion

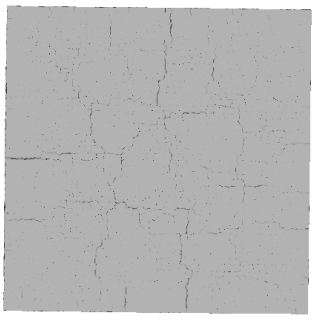


(E) Case 4: 0.8577% Expansion

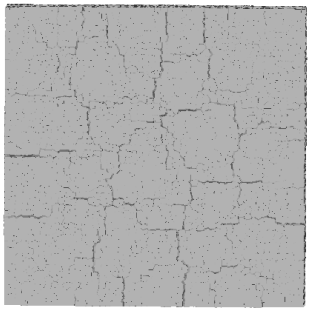
FIGURE 3: 3D Surface Cracks Expansion Intensified 75x75x75mm



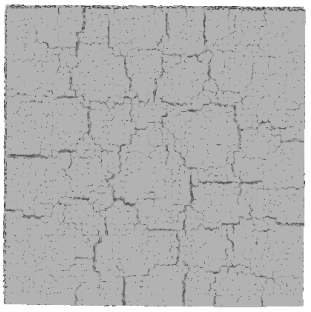
(A) Case 0: 0% Expansion



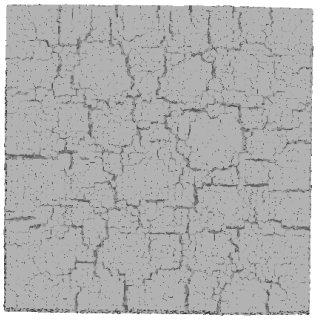
(B) Case 1: 0.1671% Expansion



(C) Case 2: 0.3380% Expansion

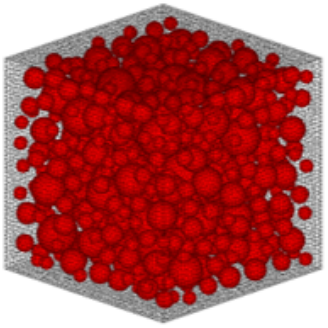


(D) Case 3: 0.5118% Expansion

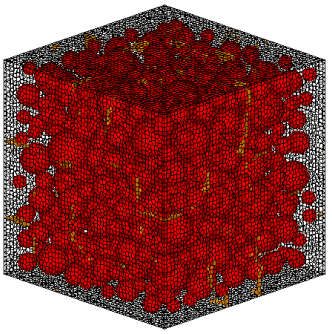


(E) Case 4: 0.8577% Expansion

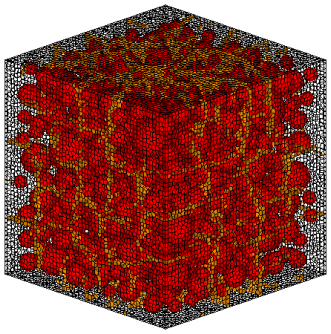
FIGURE 4: 3D Surface Cracks (Single Side View) Expansion Intensified 75x75x75mm



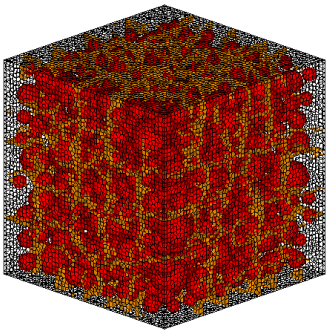
(A) Case 0: 0% Expansion



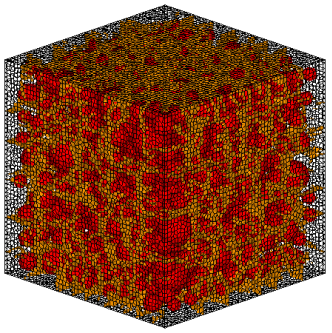
(B) Case 1: 0.1671% Expansion



(C) Case 2: 0.3380% Expansion



(D) Case 3: 0.5118% Expansion



(E) Case 4: 0.8577% Expansion

FIGURE 5: 3D Inner Cracks Expansion Intensified 75x75x75mm

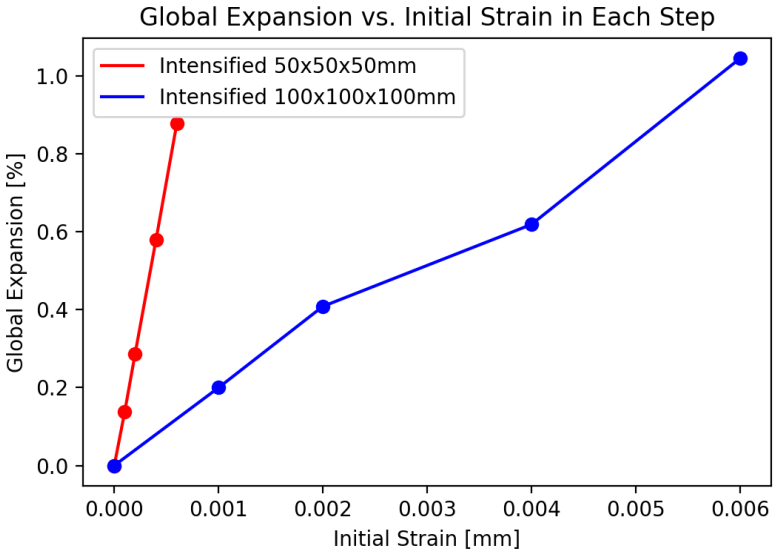
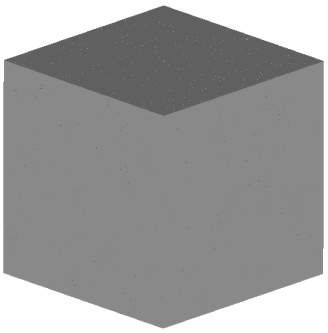
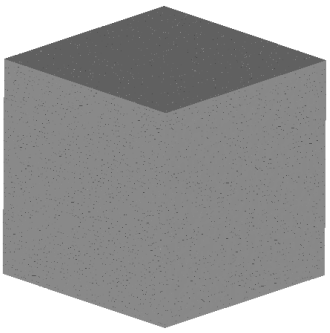


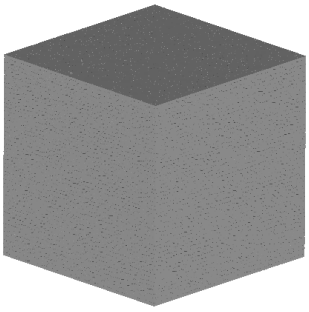
FIGURE 6: Global Expansion vs. Step



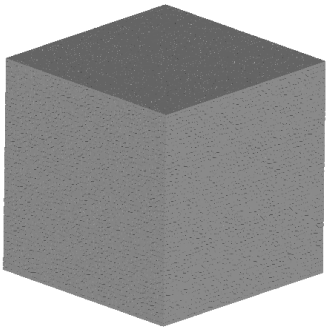
(A) Case 0: 0% Expansion



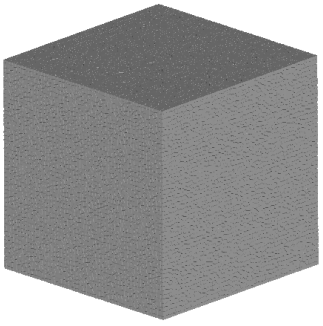
(B) Case 1: 0.2% Expansion



(C) Case 2: 0.4087% Expansion

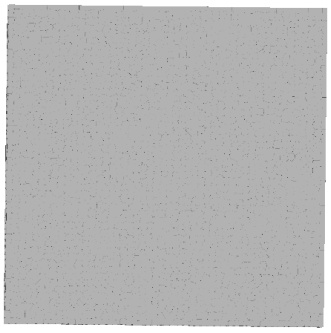


(D) Case 3: 0.6191% Expansion

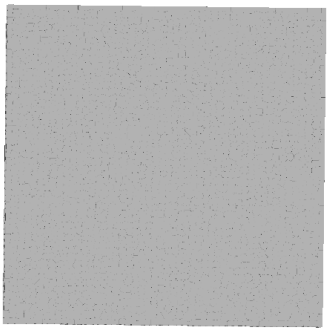


(E) Case 4: 1.0454% Expansion

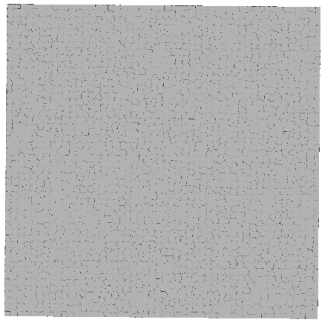
FIGURE 7: 3D Surface Cracks Expansion Intensified 100x100X100mm



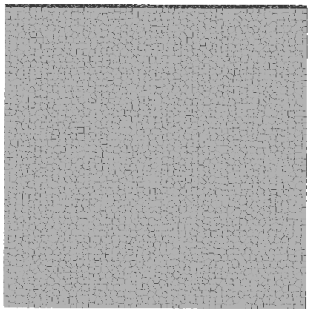
(A) Case 0: 0% Expansion



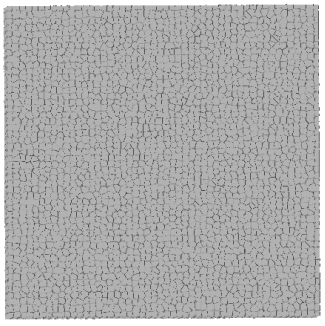
(B) Case 1: 0.2% Expansion



(C) Case 2: 0.4087% Expansion

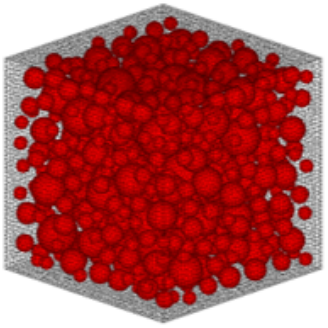


(D) Case 3: 0.6191% Expansion

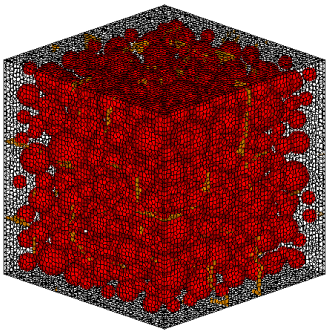


(E) Case 4: 1.0454% Expansion

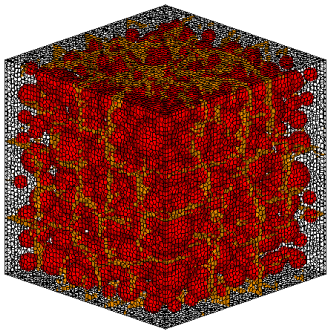
FIGURE 8: 3D Surface Cracks (Single Side View) Expansion Intensified 100x100X100mm



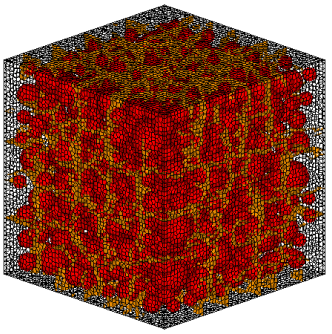
(A) Case 0: 0% Expansion



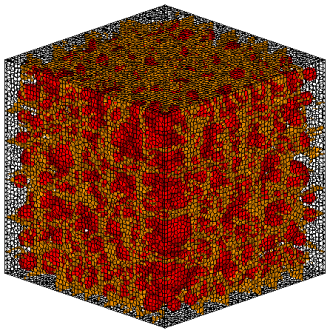
(B) Case 1: 0.2% Expansion



(C) Case 2: 0.4087% Expansion

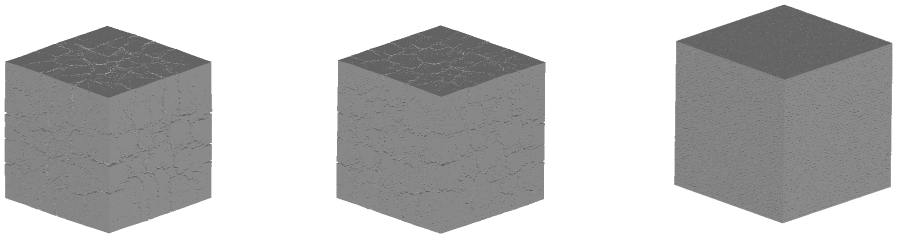


(D) Case 3: 0.6191% Expansion



(E) Case 4: 1.0454% Expansion

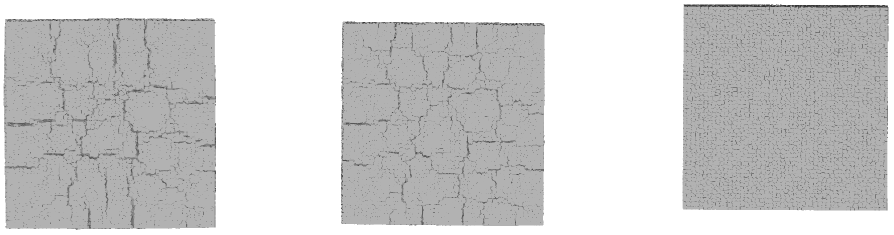
FIGURE 9: 3D Inner Cracks Expansion Intensified 100x100X100mm



(A) Intensified 50x50x50mm 0.5795% Expansion

(B) Intensified 75x75x75mm 0.5118% Expansion

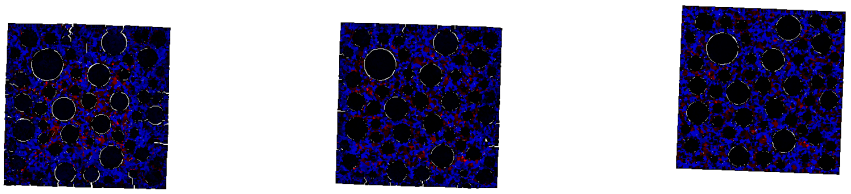
(C) Intensified 100x100x100mm 0.6191% Expansion



(D) Intensified 50x50x50mm 0.5795% Expansion

(E) Intensified 75x75x75mm 0.5118% Expansion

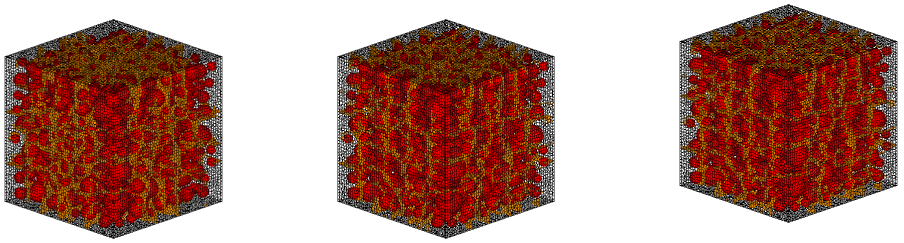
(F) Intensified 100x100x100mm 0.6191% Expansion



(G) Intensified 50x50x50mm 0.5795% Expansion

(H) Intensified 75x75x75mm 0.5118% Expansion

(I) Intensified 100x100x100mm 0.6191% Expansion



(J) Intensified 50x50x50mm 0.5795% Expansion

(K) Intensified 75x75x75mm 0.5118% Expansion

(L) Intensified 100x100x100mm 0.6191% Expansion

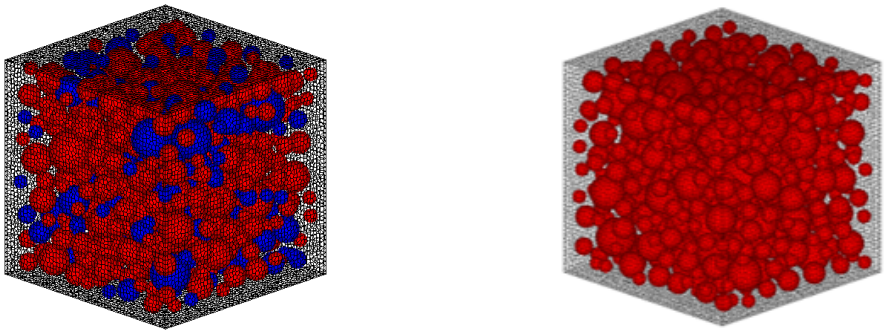
FIGURE 10: Comparing between different DEF Expansion Intensified Cases

0.1 Comparing Between ASR Expansion and DEF Expansion Simulation Result

Here the 2 expansion simulation results are compared to analysis the similarities and difference between ASR and DEF expansion.

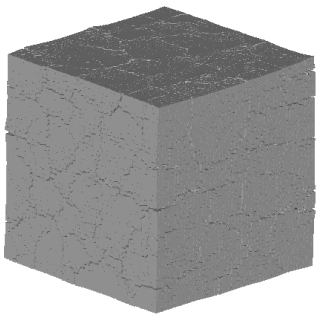
For ASR, 100x100x100mm model with 30% aggregate is chosen, of which 75% of total aggregates are ASR reactive.

For DEF, same 100x100x100mm model with 30% aggregate is using, of which the 75x75x75mm at the center part is given intensified DEF expansion, and decreased gradually in the surrounding part.

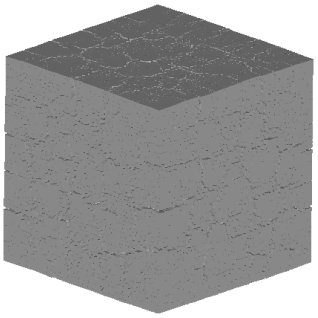


(A) Model for ASR Expansion (B) 30% Coarse Aggregate

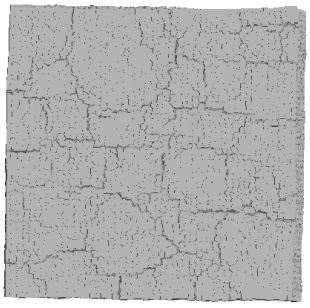
FIGURE 11: Model for DEF Expansion



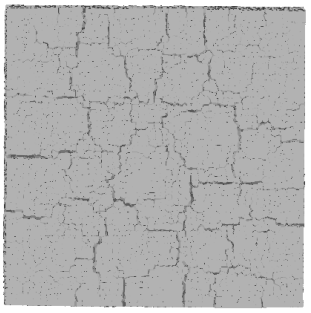
(A) 75% ASR Reactive Aggregate, 3D Surface Cracks, 0.4223% Expansion



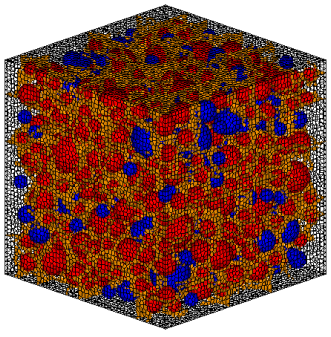
(B) 75x75x75mm Intensified, 3D Surface Cracks, 0.5118% Expansion



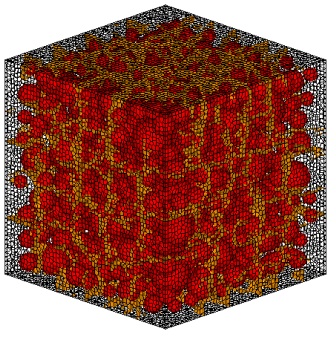
(C) 75% ASR Reactive Aggregate, Surface Sideview, 0.4223% Expansion



(D) 75x75x75mm Intensified DEF, Surface Sideview, 0.5118% Expansion



(E) 75% ASR Reactive Aggregate, Inner Crack, 0.4223% Expansion



(F) 75x75x75mm Intensified DEF, Inner Crack, 0.5118% Expansion

FIGURE 12: Cracks Compare Between ASR Expansion and DEF Expansion Simulation Result

From Figure it can be seen that at a relatively close global expansion ratio, the surface cracking pattern of ASR expansion and DEF expansion can be very close.

However, the inner crack distribute is not exactly the same in these 2 cases. Clear cross alike distribution can be seen in DEF expanded case but not in ASR case.

This can also be confirmed by the cross-section view (Figure 13), where in middle of each face of DEF expanded model concentration of crack perpendicular to surface is shown. Besides, for the DEF expansion, the inner part of the model is more integrated comparing to ASR case, with almost no crack inside.

This may indicate with similar outside cracking damage level, deteration caused by DEF expansion is less severe compared with ASR expansion.

(A) 75% ASR Reactive Aggregate, Cross Section, 0.4223% Expansion

(B) 75x75x75mm Intensified DEF, Cross Section, 0.5118% Expansion

FIGURE 13: Cross Section Compare Between ASR Expansion and DEF Expansion Simulation Result

Crack Width [mm]	ASR A30P75 0.4223% Expansion Total Cracked Interfaces	DEF A30I75 0.5118% Expansion Total Cracked Interfaces
0.00000 - 0.00005	316744	373019
0.00005 - 0.00010	286704	335814
0.00010 - 0.00020	263943	299690
0.00020 - 0.00050	234672	249242
0.00050 - 0.00100	183238	177030
0.00100 - 0.00300	131553	113350
0.00300 - 0.01000	42432	42207
0.01000 - 0.03000	275	240
0.03000 - 0.10000	0	0
0.1000+	0	0

TABLE 3: Expansion in Each Step for A30 P75 Case 3

PLOT

When comparing the cracked interfaced grouped by the width of crack (Tabel 3), it also can be seen that comparing to ASR expansion, cracks in DEF expansion simulation result is more concentrated in smaller crack width, which is under 0.001mm in this comparison.

ASR and DEF expansion, though similar on their surface cracking, are different in their mechanism and inner condition. And the simulation used in this research can properly reproduce not only the similarities but also the difference between them.