AGGREGATE INTERLOCK CYCLIC RESPONSE OF R.C. CRITICAL SECTION

L. Briseghella (I)
R. Gori (I)
Presenting author: R. Gori

SUMMARY

The results of numerous laboratory tests on cracked concrete with pre-fixed amplitude elements and generalized action subjects are presented in this paper. Because of loading and general displacement patterns, the experimental responses in function with cyclic degrading and alternating, and with the variation of dissipated energy in different cycles are analysed. Further experimental tests are advisable.

0. Introduction

In R.C. critical sections, there are 3 distinct mechanisms of shear transfer: a) shear forces across the compression zone; b) dowel force transmitted across the crack by flexural reinforcement (plus a component of axial forces in reinforcing bars inclined towards the crack direction); c) interface shear transfer (IST) on the rough surfaces of the crack by means of the aggregate particles interlocking (Ref.1).

The IST mechanism was experimentally studied by various authors (Ref.2) and we know that there are analytic mathematical models with finite elements coming from the literature of reinforced concrete structures for simulating pre-defined cracks (Ref.3), from the literature of geomechanics for simulating interface joints between rock masses (Ref.4), from the literature of contact-impact problems for the behaviour of interfaces (Ref.5).

The research reported in this paper concerns an extended experimental investigation into concrete cracks, bearing monotonic, alternate and reversed shear actions. Particular attention is given to the influence of various parameters such as initial crack width, shear stiffness, changes in the shear histeresis loop with cycling, capacity of absorbing and dissipating energy.

1. Experimental Set Up

The experimental test equipment is shown in Fig.1a and was set up by Padua University's Istituto di Scienza delle Costruzioni's Experimental Laboratory. The reading of the force is effectuated by a 100 kN Hottinger load cell. The reading of the orthogonal force in relation to the crack is effectuated by means of 4 strain gages, BLH Type SR-4, Model FAE-25-12-S6EL. The reading of the displacements relative to the crack faces is effectuated by 2 couples of transducers (DDI) by the firm Hottinger, automatically mediating the coupled values of the displacements. All the survey instruments are connected to a Hottinger surveyor which controls an X,Y, plotter, by the firm Rikadenki. The transversal stiffness of the connection by the 4 external forces Ø20 results as K_t = 924 kN/cm (Ref.6).

(I) Istituto di Scienza delle Costruzioni, University of Padua, Engineering Faculty, Via Marzolo, 9, 351000 Padua, Italy.

2. Material and Specimen

Numerous tests of various types were carried out on 24 specimens of concrete, with dimensions of 200 x 200 x 200 mm, and with a cylindric resistance of 36 MPa, initial normal elasticity modulus E = 35000 MPa (cement = 2.4 kN, water = 1.5 kN, sand = 4.0 kN, gravel = 9.0 kN), mean Split Cylinder Test = 152 kN. The specimens' crack is created by a compression machine with the Split Cylinder Test interposing 2 bars Ø20 mm between the machine's plates. The fracture line obtained(by traction) passes through the cement layer and also numerous elements of gravel which break as a result.

3. Results of the Monotonic Tests

The results of the Monotonic Tests obtained as the average of 4 experiments are shown in fig.2. The different initial amplitudes imposed on the fracture are indicated w= 0.0 ÷ 0.5 ÷ 1.0 mm.

The indicated behaviour results strongly as being non-linear with the combination of various parameters (fig. 2a,b,c,d).

In fig.2e, the shear displacement bond versus normal displacement is indicated and in fig. 2f it is accompanied by normal stress. These 2 bonds depend on the particular transversal stiffness of the adopted equipment and on the particular type of crack.

4. Results of the Cyclic Tests (without inversion)

The results of the cyclic tests (without inversion) with limitation of the shear stress and obtained for initial amplitude of the crack w = 0.0 ÷ 0.5 ÷ 1.0 mm are shown in fig.3.

The shear displacement versus shear stress relationship is indicated in fig.3a; it can be noted that after 55 cycles there is still no saturation of the hysteresis curve.

Once again the shear displacement versus shear stress is shown in fig.3e for an initial opening of the crack w = 0.5 mm.

5. Results of the Alternate Cyclic Tests (cycles of shear stress)

Shown in fig.4 are the results of the alternate cycle tests carried out on 2 limits of symmetrical shear stress, for initial crack amplitudes w = 0.0 ÷ 0.5 ÷ 1.0 mm.

In fig.4a it can be seen how the shear displacements increase from the first to the sixth cycle, and how the tangent stiffnesses vary, in fig.4b, the experimental bonds between shear displacement and normal stress, because of tests carried out using equipment with a transversal rigidness of K_t = 924 kN/cm. It should be noted how normal stress and normal displacements do not cancel each other during the alternating of the shear displacement cycles. It should also be noted that as for the paths of shear symmetrical stress, the paths of the other parameters are asymmetric and show a strong dependence on the loading path.

6. Results of the Incremental Alternate Cyclic Tests of Deformation (with 5 Loops for each increment).

In fig.5a,b,c,d, the results of the alternate cyclic tests on different incremental limits of deformation can be seen, after having done 5 alternating loops for each cycle of imposed deformation. Tension degrading because of imposed shear displacement cycles is represented in these diagrams. The indicated tests are conducted for the beginning of opening of the crack $w = 0.0 \div 0.5 \div 1.0$ mm. The shear displacement path shows how, after degrading, the material moves nearer the monotonic curve when the shear displacements grow, for the various parameters.

7. Conclusions and Recommendations

The main conclusions of this paper are as follows:

a) the shear stress - shear slip relationship for interface shear transfer at a crack in reinforce concrete becomes highly non-linear, with cycling path, the differences degrade; the displacements increase, and the capacity of absorbing and dissipating energy changes with the hysteresis loop.

b) the energy absorbed in the various cycles of hysteresis, referring to the dissipating energy in the first cycle, decreases (fig.5e).

c) the relationship between the work of the normal stress and normal displacement and total work, (normal plus transversal), and the varying of the number of cycles, indicates how practically all the enegy is absorbed by the shear stress for the vonjugate shear displacements (fig.5b).

d) the shear displacements and normal displacements increase with the number of cycles per alternatly inverted test between values of locked and symmetrical shear stress.

The complete interpretation of the various results will allow the formation of a contact finite element; governed by a law type $d\underline{\sigma}_n = \underline{\underline{K}}\, d\underline{\delta}$ with $\underline{\underline{K}}$ incremental matrix of stiffness, non-linear, asymmetrical which will be presented in a subsequent paper.

The continuation of IST experimental tests is advised, with equipment of different transversal stiffnesses, with initial opening of the unparallel crack and with types of fractures with different roughnesses.

R E F E R E N C E S

1. Scarpas, A. & Tassios, T., "Shear Transfer Trough Cracked Reinforced Concrete Sections", Progress Report, Greek-Soviet Bilateral Research Project, Oct., 1982

2. Jimenez, R. & White, R.N. & Gergely, P.,"Cyclic Shear and Dowel Action Models in R/C", Jnl St. Div., ASCE, Vol. 108, St5, May,1982

3. Bazant, Z.P. & Gambarova, P., "Rough Cracks in Reinforced Concrete", Jnl St. Div., ASCE, St4,April, 1980

4. Goodman, R.E. & Taylor, R.L. & Brekke, T.L., "A Model for the Mechanics of Jointed Rock", Jnl Soil Mech. and Found Div., ASCE, SM3, May, 1968

5. Ricketts, R.E. & Zienkiewicz, O.C., "Preformed Cracks and their Influence on Behaviour of Concrete Dams", pp 1127-1148, Ed. Naylor, Stagg & Zienkiewicz, Proceeding of Int. Symp. held at Swansea, United Kingdom, 1975

6. Briseghella, L. & Gori, R., "Indagine sperimentale sul comportamento della frattura di conglomerato cementizio in presenza di azioni monotoniche e cicliche", Istituto di Scienza delle Costruzioni, Univ. of Padua, Italy, 1983

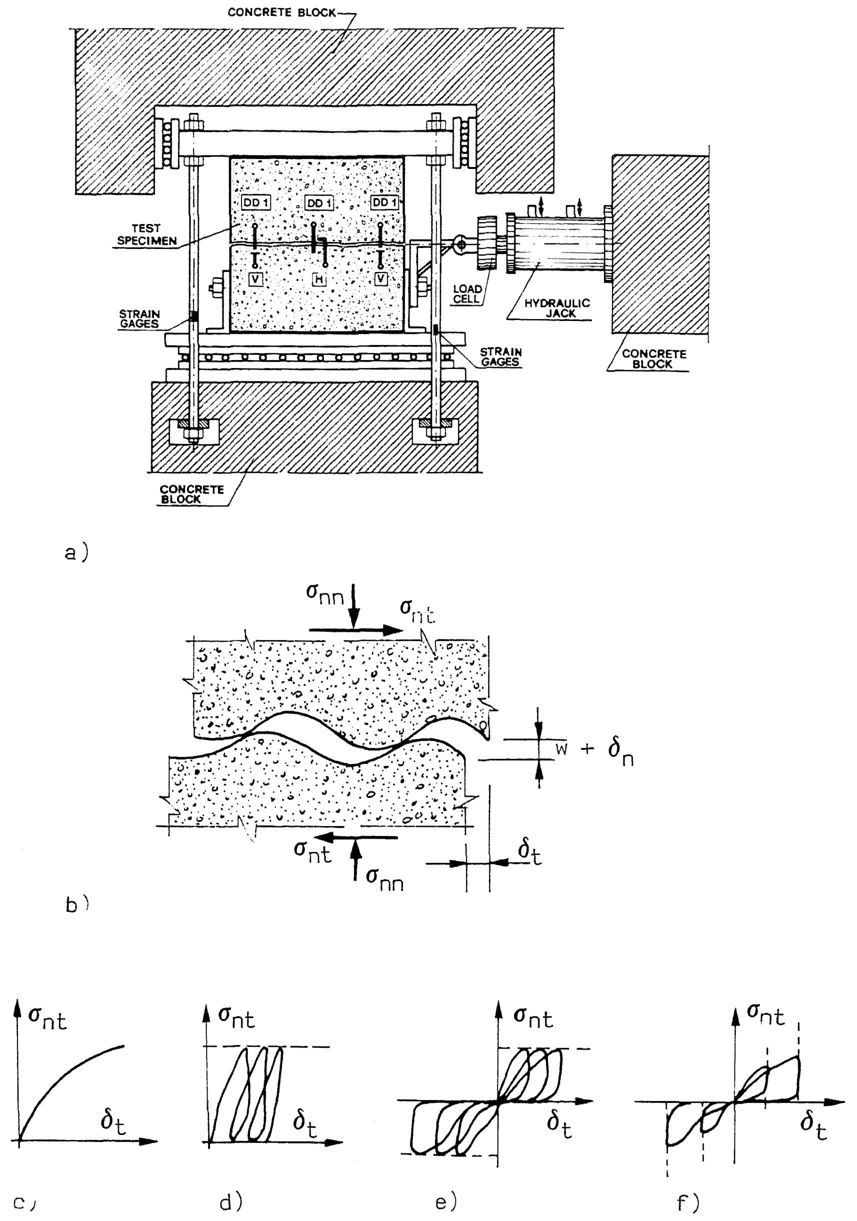

Fig. 1 a) Experimental Setup; b) Definition of Stress and Displacement; c) Monotonic Response; d) Cyclic Response; e) Cyclic Inverted Response (Stress Bound); f) Cyclic Inverted Response (5 iterations per Displacement Bound).

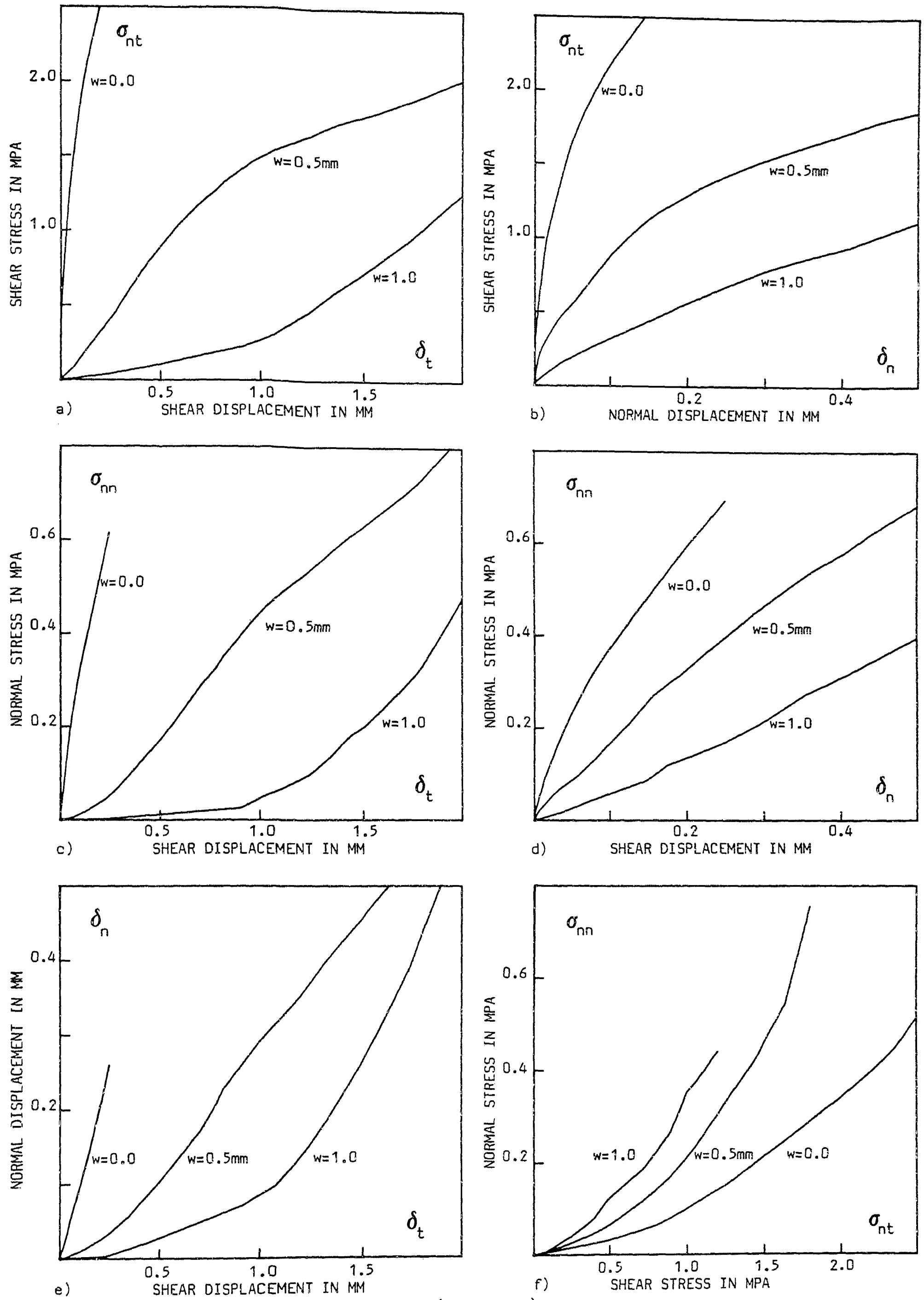

Fig. 2 Mean Monotonic Response (4 tests).

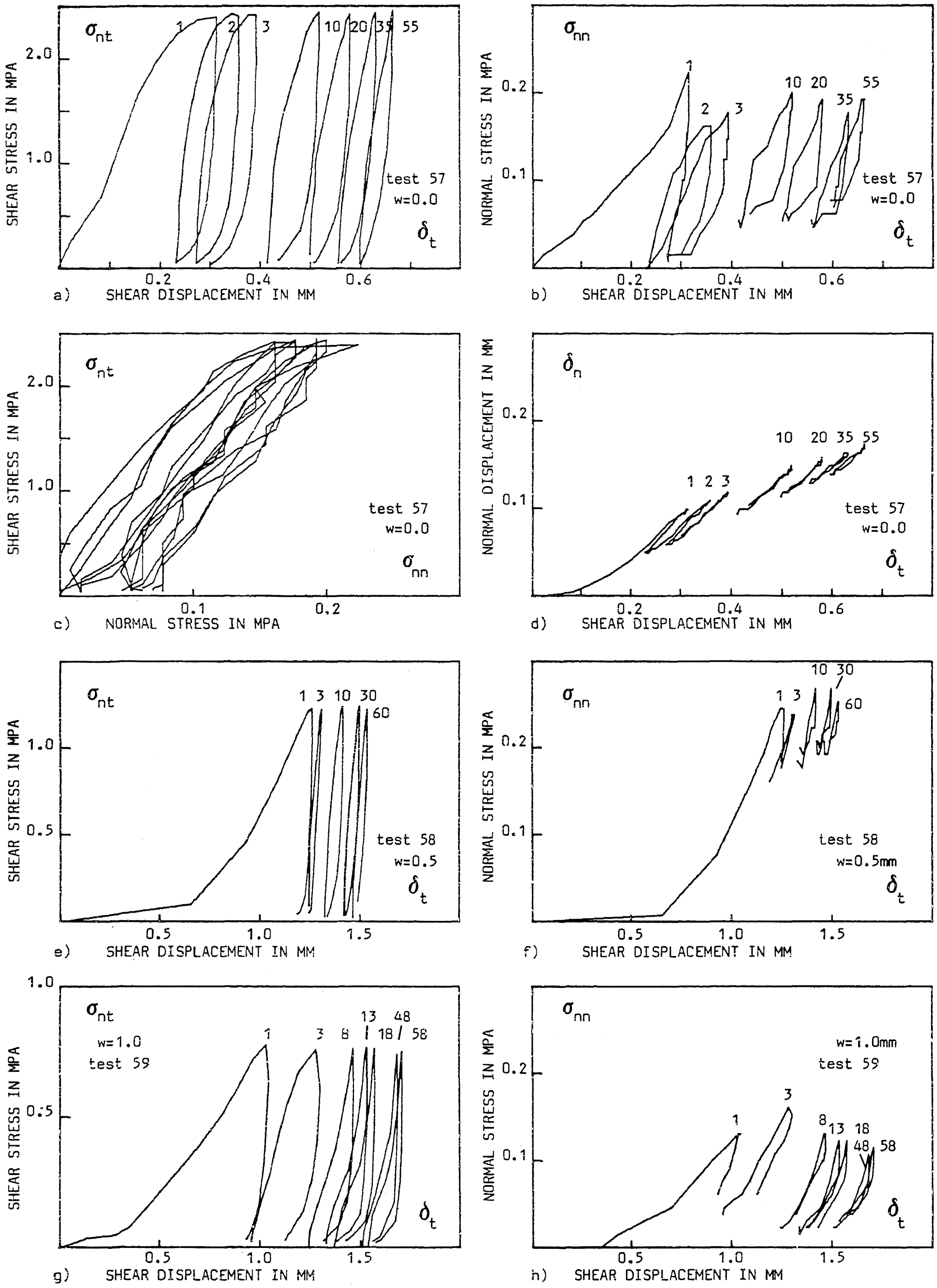

Fig. 3 Cyclic Response with Crack Width = 0.0 ÷ 0.5 ÷ 1.0 mm.

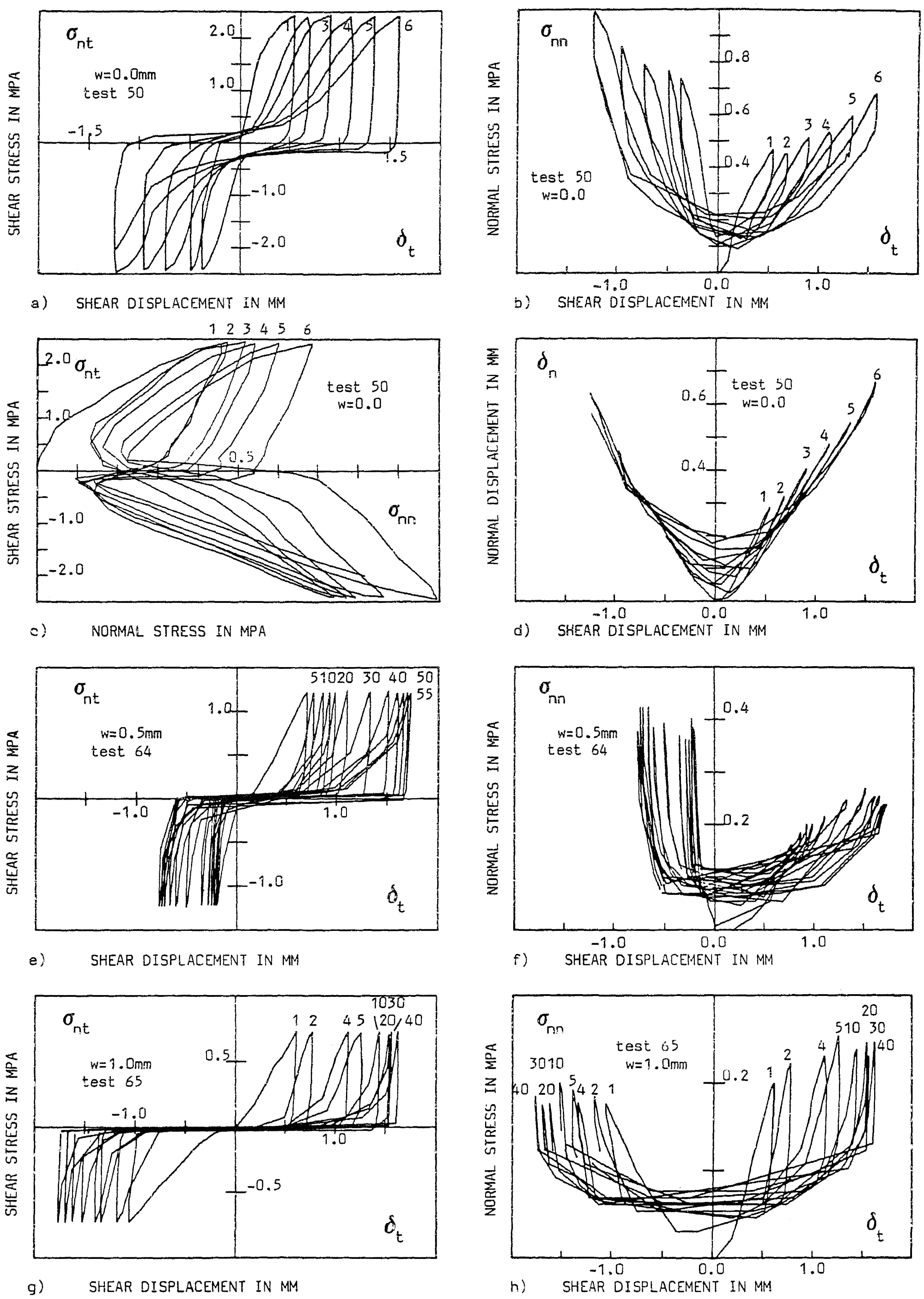

Fig. 4 Alternate Cyclic Response with Crack Width = 0.0 ÷ 0.5 ÷ 1.0 mm.

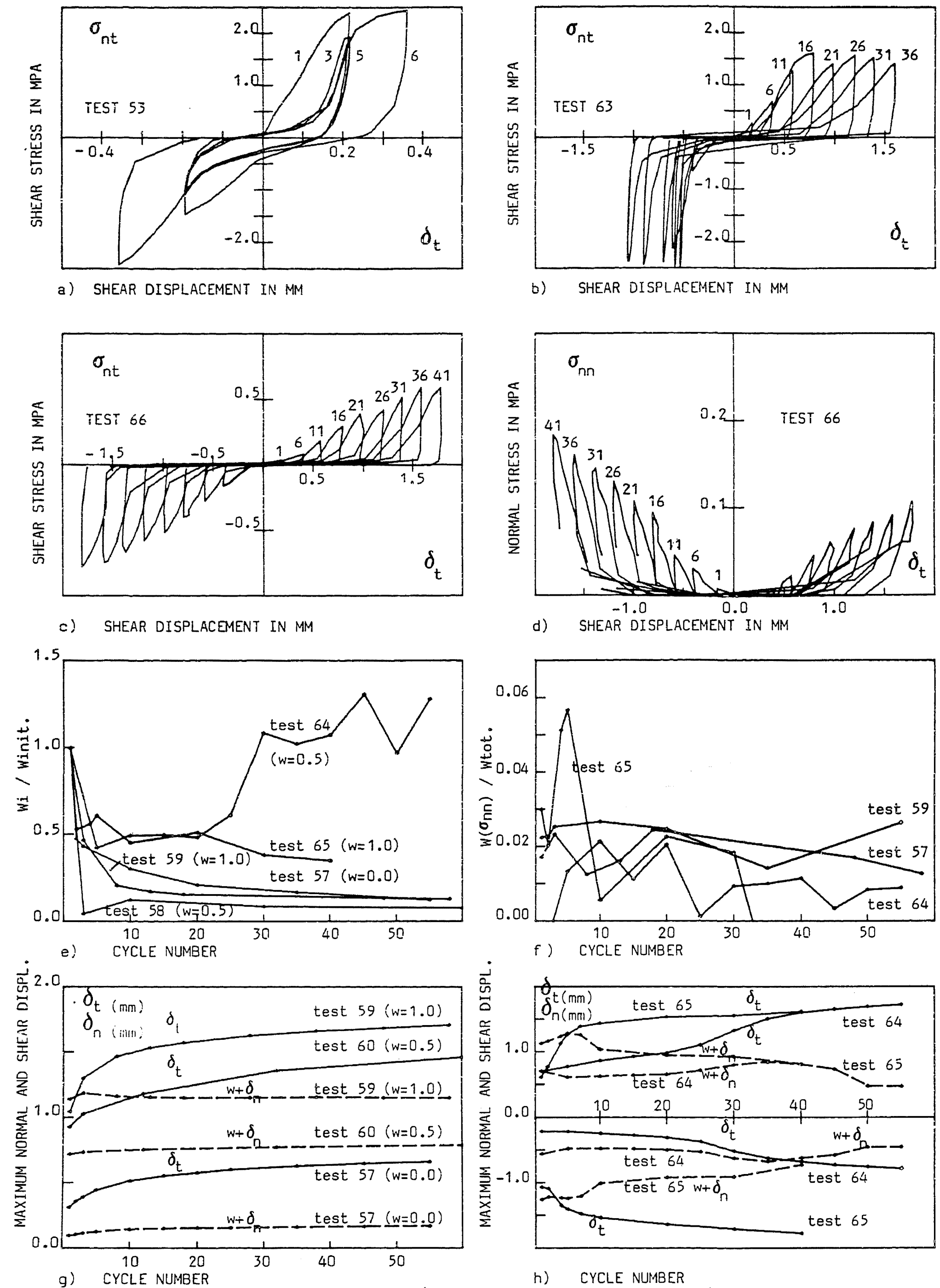

Fig. 5 Alternate Cyclic Response (Displacement Controlled) with Crack Width = 0.0 ÷ 0.5 ÷ 1.0 mm and Normalized Energy Response.