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Prediction of non-proportionality factors and equivalent ranges of multiaxial histories using the moment of inertia method

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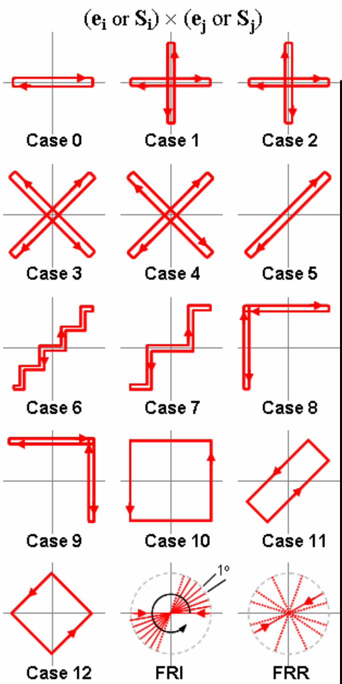
This work studies further an approach to evaluate equivalent stress and strain ranges in non-proportional (NP) histories, called the Moment Of Inertia (MOI) method. The MOI method, proposed by the authors in [1], assumes that the path contour in the deviatoric stress or strain diagram is a homogeneous wire with unit mass. The center of mass of such wire gives then the mean component of the path, while the moments of inertia of the wire can be used to obtain the equivalent stress or strain ranges. The MOI method is an alternative to convex enclosure methods, such as the Minimum Ball or Maximum Prismatic Hull methods, without the need for computationally-intensive search algorithms or adjustable parameters. The MOI method can deal with an arbitrarily shaped history without losing information about such shape, as opposed to a convex enclosure method. Therefore, it can be successfully used even in highly non-convex stress or strain NP history paths such as cross or star-shaped paths, which result in poor predictions when convex enclosure methods are used. The MOI method is relatively simple, intuitive, and easy to implement and to compute, therefore it should be considered as an alternative engineering tool to deal with NP histories. Coupled with a multiaxial rainflow algorithm such as [2], it is able to deal with very long variable amplitude histories, which would be too computationally intensive for incremental plasticity or convex enclosure methods to obtain stress or strain ranges. In this work, the MOI method is also generalized to calculate as well the non-proportionality factor Fnp of a loading history, using an alternative sub-space of the deviatoric stresses or strains. Experimental results for the 15 different multiaxial histories from [3] prove the effectiveness of the MOI method not only to predict the associated fatigue lives, but also to predict the observed non-proportionality factors, as seen in Figure 1.

[1] Meggiolaro, M.A., Castro, J.T.P., An Improved Multiaxial Rainflow Algorithm for Non-Proportional Stress or Strain Histories - Part I: Enclosing Surface Methods, International Journal of Fatigue , in press, 2011.

[2] Wang, C.H., Brown, M.W., Life prediction techniques for variable amplitude multiaxial fatigue - part 1: theories. Journal of Engineering Materials and Technology 118, pp.367-370, 1996.

[3] Kida, S., Itoh, T., Sakane, M., Ohnami, M., Socie, D.F., Dislocation structure and non-proportional hardening of type 304 stainless steel, Fatigue and Fracture of Engineering Materials and Structures, v.20, n.10, pp.1375-1386, 1997.



path / F_{np}	low Δε .35-.5%	high Δε .7–.8%	MOI	Itoh-Socie
Case 0	0	0	0	0
Case 1	0.70	0.59	0.48	0.34
Case 2	0.59	0.47	0.48	0.34
Case 3	0.73	0.62	0.57	0.39
Case 4	0.83	0.62	0.57	0.39
Case 5	0	0	0	0
Case 6	0.12	0.14	0.10	0.10
Case 7	0.26	0.27	0.20	0.20
Case 8	0.83	0.70	0.81	0.77
Case 9	0.77	0.76	0.81	0.77
Case 10	0.81	0.70	0.81	0.77
Case 11	0.30	0.48	0.45	0.46
Case 12	0.59	0.56	0.70	0.77
FRI	0.81	0.35	0.5 – 1.0	0.32
FRR	1.00	0.90	0.9 - 1.0	0.32

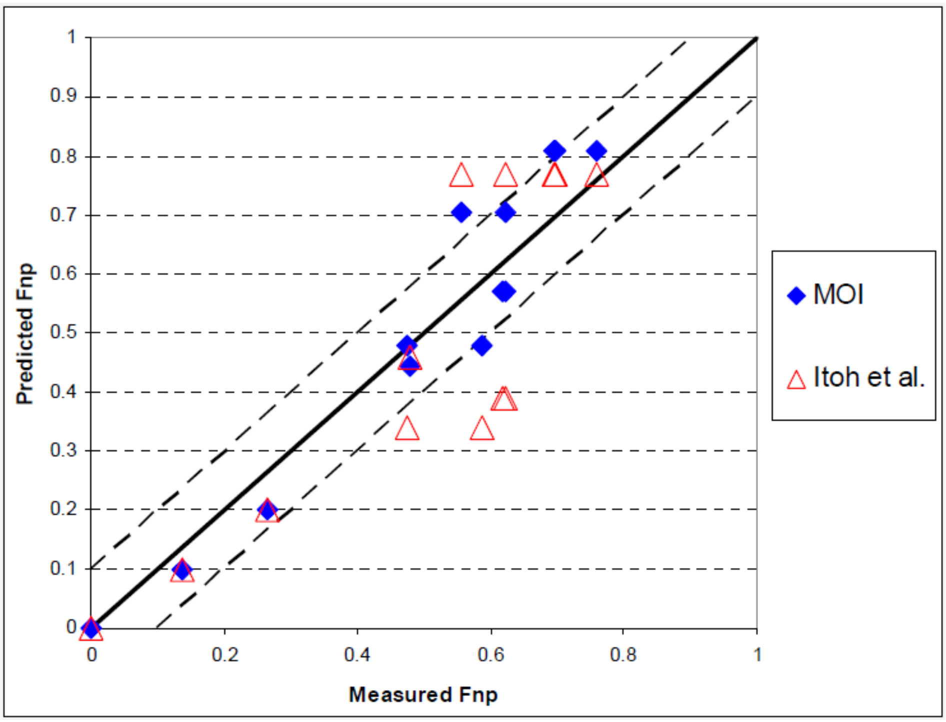


Figure 1 - Predicted and measured Fnp from the MOI and Itoh-Socie's integral methods, for a 304 stainless steel at strain range levels between 0.7% and 0.8%.

Keywords: non-proportional loading, equivalent range prediction, non-proportionality factor prediction, multiaxial fatigue life prediction