Copyright © 1996 Elsevier Science Ltd
Paper No. 635. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

EFFECT OF BRITTLE MASONRY INFILLS ON DISPLACEMENT AND DUCTILITY DEMAND OF MOMENT RESISTING FRAMES

C.V.R. MURTY
Department of Civil Engineering
Indian Institute of Technology Kanpur
Kanpur 208016, India

and

A. NAGAR
Tata Consultancy Services
IV Floor Gulab Bhavan, Bahadur Shah Zafar Marg
New Delhi 110002, India

ABSTRACT

In the seismic design of frame buildings, it is usually assumed that non-structural elements do not contribute to strength and stiffness. Masonry infill walls, which are very brittle and which may get severely damaged during strong shaking, are often treated as non-structural elements. The cyclic load-deflection data from experiments show that infills continue to govern the overall response of the structure even after cracking. Based on the ductility reduction factor (DRF) spectra obtained in a recent parametric study, this paper shows that brittle unreinforced masonry (URM) infill walls have some important beneficial effects in the seismic design of reinforced concrete (RC) moment-resisting frames (MRFs) *vis-à-vis* the displacement and ductility demands on the frame members. A simple example is used to demonstrate that such infills significantly reduce the ductility demand on the frame members.

KEYWORDS

Ductility; Ductility Reduction Factor; Hysteretic Behaviour; Inelastic Response; Infilled Frames; Moment Resisting Frames; Reinforced Concrete; Seismic Response.

INTRODUCTION

The URM brick infill walls in RC MRF buildings contribute significant strength and stiffness. However, the infills are brittle and loose their strength at relatively small lateral displacements. Hence, in the design of such buildings, it is a usual practice to treat the infills as non-structural elements and often ignore the strength contributed by these infills. Also, nonlinear studies on such building structures ignore the strength as well as the stiffness contribution of infills. However, it is recognized that the enhanced strength and stiffness of the filler walls until they are cracked alters the course of the nonlinear response, in particular the maximum displacement experienced by the frame. This paper focuses on the relief offered by the infills as regards displacement and ductility demands when the bare frame and infill composite properties are considered in evaluating the inelastic response spectrum. The results of a recent study (Nagar, 1995) are used in drawing these inferences.

An infilled frame, in general, exhibits both higher lateral stiffness (*e.g.*, Jain *et al.*, 1995) and larger maximum lateral load capacity (*e.g.*, Pires and Carvalho, 1992) than that estimated from the analysis of bare frames. The increase in stiffness and enhancement in strength cause larger dissipation of input seismic energy with progressive cracking of infills. The limited experimental data available for masonry infilled frames (Brokken and Bertero, 1981; Gergely, *et al.*, 1994; Klinger and Bertero, 1976; Kwan, *et al.*, 1990; Liauw, 1979) indicate a load-deformation relationship of the type shown in Fig.1. Clay brick masonry being a grossly heterogeneous material, these experimental results indicate a very wide range of scatter. While most results are for monotonic loading, some results are also available for reversed cyclic loading. However, not much work has been reported on the analytical modeling of the hysteretic response of masonry infilled frames. Inelastic response spectrum and ductility reduction factor studies are often based on bilinear load-deformation relationships, in particular, elastic perfectly-plastic response. It is of interest to see how the inelastic response spectrum and ductility reduction factor are affected under the load-deflection relationship of the type applicable to infilled frames (Fig.1).

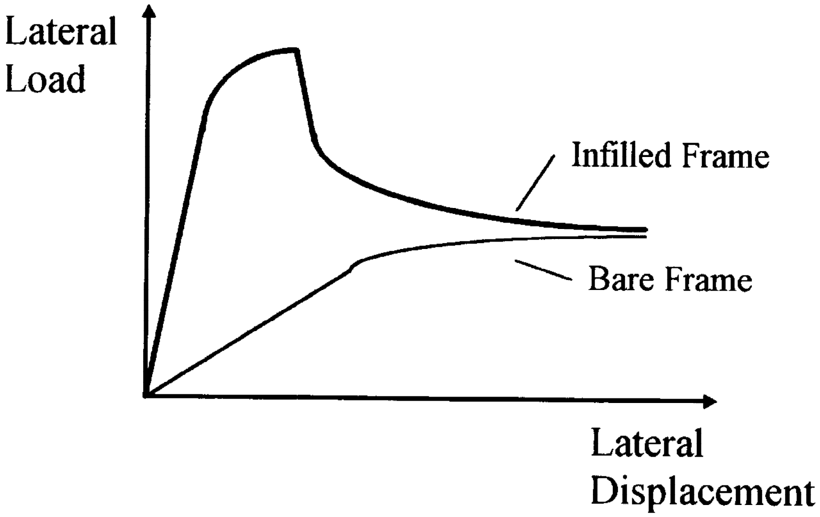

Fig.1 : Typical Lateral Load-Displacement Curves of Infilled and Bare Frames

DRF SPECTRUM FOR INFILLED FRAMES

Considering the limited experimental data available in literature, a simple Trilinear Hysteresis Model was proposed (Nagar, 1995) to capture the hysteretic response of URM infilled RC MRFs. The monotonic lateral load-displacement curve for the URM infilled frame was idealized by the trilinear curve shown in Fig.2. The influencing parameters are the yield strength (P_y^{if}) corresponding to the maximum load carrying capacity, the ultimate strength (P_u^{if}), the initial elastic stiffness (K^{if}) and the negative slope (K_n^{if}). The simplified hysteresis model provides for gradual reduction in the loading and unloading stiffnesses from that of the infilled frame to that of the bare frame. The effects of relaxation, strain hardening and stiffness degradation are not considered. Using this model, the inelastic response spectra of 24 strong ground motions recorded during the 1991 Uttarkashi (India) earthquake (Jain and Das, 1993) were obtained. Using these, the mean DRF spectra were obtained.

Owing to the large scatter in the available experimental data, a parametric study was conducted (Nagar, 1995) to study the behaviour over a wide range of parameters. The ratio (K^{if}/K^{bf}) of the stiffness of the infilled frame (K^{if}) to that of the corresponding bare frame (K^{bf}) may be as high as 10, depending on the characteristics of masonry, mortar, thickness of infill, dimensions of frame members, presence and size of openings, and the prevalent construction practices. The study considered values of 2, 5 and 10 for the stiffness ratio. The strength ratio (P_y^{if}/P_u^{if}) of the maximum load capacity (P_y^{if}) of the infilled frame to its ultimate load capacity (P_u^{if}), also depends on these very factors. This ratio may be as high as 2. Strength ratio values of 1.0, 1.25, 1.5, 1.75 and 2.0 have been considered. Brittleness of the infill walls is reflected by the slope ratio (K_n^{if}/K^{if}) of the negative slope (K_n^{if}) in the unstable region to the initial elastic stiffness (K^{if}) of the backbone curve (Fig.2). In case of brittle masonry, the negative slope could be very high owing to a sudden drop in the load once the masonry cracks. Slope ratios of 1000, 2, 1 and 0.2 have been used.

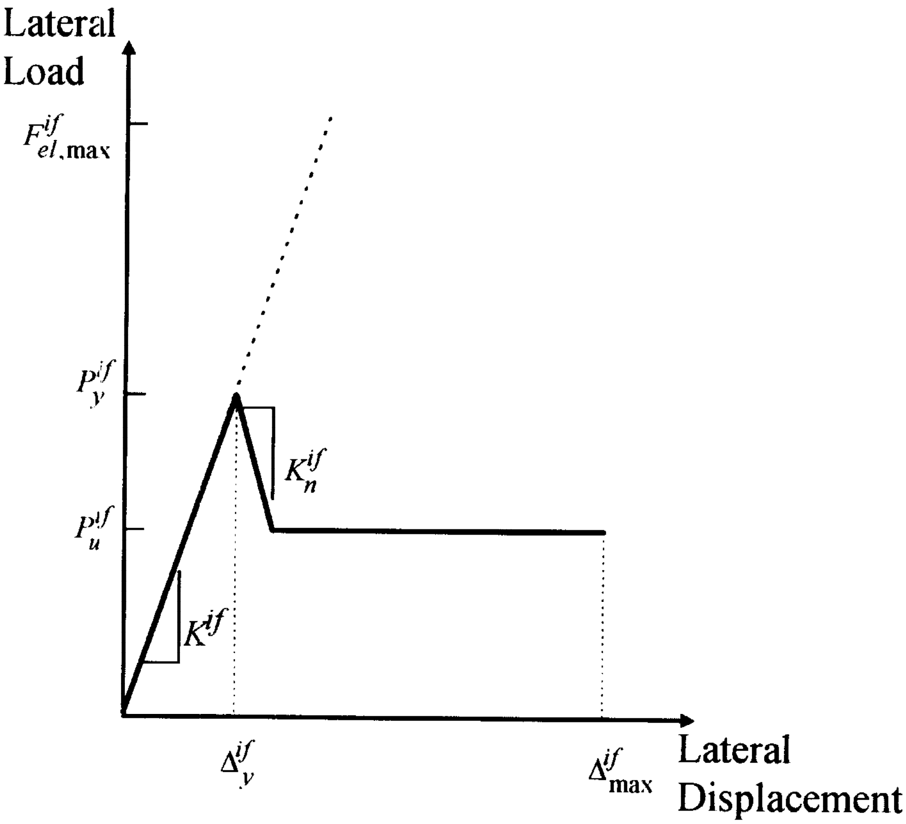

Fig.2 : Idealized Monotonic Backbone Curve used in the Trilinear Hysteresis Model (Nagar, 1995).

For the idealized monotonic lateral load-displacement relation shown in Fig.2, ductility (μ) has been defined as the ratio ($\Delta_{max}^{if}/\Delta_y^{if}$) and ductility reduction factor (R_μ^{if}) as the ratio ($F_{el,max}^{if}/P_y^{if}$), where $F_{el,max}^{if}$ is the maximum force that would be generated in the structure if it were to remain elastic. The results are presented in the form of mean DRF spectra for different values of the parameters. One set of the mean DRF spectra for specific values of the parameters is given in Fig.3. The DRF spectrum for the bare frame is also included alongwith. The natural period values on the horizontal axis of the DRF spectra for infilled frames correspond to their initial elastic stiffness. The spectra correspond to a damping ratio of 5%. The ductility values studied are 1, 1.5, 2, 3, 5, 8, 10, 12 and 15.

DESIGN IMPLICATIONS

The DRF values given by Fig.3 show that for natural periods larger than 0.5 sec, R_μ^{if} is about the same as the ductility (μ). This is similar to the DRF spectra reported by Riddel *et al.* (1989) for elastic-perfectly plastic systems. Since the yield force for the infilled frame is more in comparison with that of the bare frame, R_μ^{if} required is less, and hence μ required is less. Further, since the yield displacement of the infilled frame itself is less owing to higher stiffness, the maximum displacement experienced is considerably less than that by a corresponding bare frame. Hence, the beams and columns of the frame undergo less maximum deformations

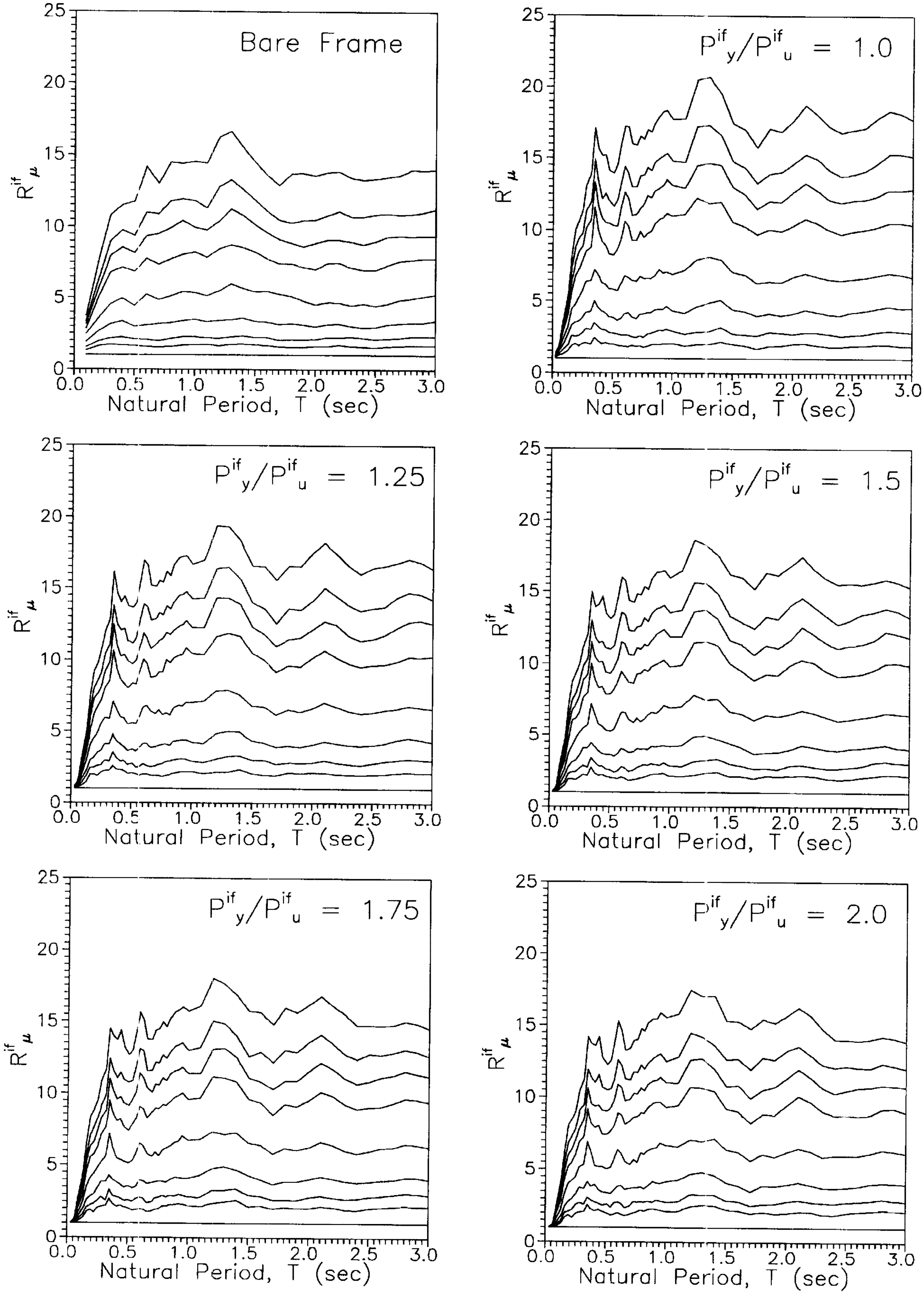

Fig. 3. Mean DRF Spectra of Uttarkashi earthquake strong motion records, for URM RC infilled frames with stiffness ratio $K^{if} / K^{bf} = 10$ and slope ratio $K_n^{if} / K^{if} = 1000$. Mean DRF spectra of bare frames are also shown. The spectra correspond to ductility values of 1, 1.5, 2, 3, 5, 8, 10, 12, and 15. (Nagar, 1995)

and displacements owing to the presence of panels, and are able to sustain the earthquake forces with less damage.

On the other hand, the infilled frame, which is stiffer than the bare frame, may attract higher elastic force ($F^{if}_{el,\max}$). But, that effect does not seem to offset the relief provided by the infills due to that above effect.

EXAMPLE

Consider an infilled frame. Let the corresponding bare frame (*i.e.*, with infill strength and stiffness ignored) have a natural period (T^{bf}) of 0.5 *sec*. Let the yield displacement (Δ^{bf}_y) of the bare frame be 4 *mm* and the maximum force ($F^{bf}_{el,\max}$) generated in the bare frame if it were to remain elastic be 3000 *kN*. Let its design ductility (μ^{bf}_{design}) be 5. Assume that when infills are considered, the backbone curve of Fig. 3 has a stiffness ratio (K^{if}/K^{bf}) of 10, a strength ratio (P^{if}_y/P^{if}_u) of 2, and a slope ratio (K^{if}_n/K^{if}) of 1000.

The maximum displacement experienced by the bare frame is simply

$$\Delta^{bf}_{\max} = \Delta^{bf}_y \times \mu^{bf}_{design} = 4 \times 5 = 20\ mm. \tag{1}$$

For the design ductility (μ^{bf}_{design}) of 5, the ductility reduction factor (R^{bf}_μ) for the bare frame is estimated to be 5 using the relations given in literature [Riddel *et al.*, 1989]. Hence, the design yield force for the bare frame is

$$P^{bf}_y = F^{bf}_{el,\max} \big/ R^{bf}_\mu = 3000/5 = 600\ kN. \tag{2}$$

The natural period of the infilled frame is given by

$$T^{if} = T^{bf}\sqrt{\frac{K^{if}}{K^{bf}}} = 0.5\sqrt{\frac{1}{10}} = 0.16\ \text{sec}. \tag{3}$$

The initial stiffness of the infilled frame is 10 times that of the bare frame; further, yield strength of the infilled frame is 2 times that of the bare frame. Hence, the yield force and yield displacement of the infilled frame are

$$P^{if}_y = 2 \times P^{bf}_y = 2 \times 600 = 1200\ kN \tag{4}$$

$$\Delta^{if}_y = \frac{P^{if}_y}{K^{if}} = \frac{2 \times P^{bf}_y}{10 \times K^{bf}} = \frac{2}{10} \times (4) = 0.8\ mm. \tag{5}$$

Assuming that the elastic spectral acceleration due to the ground motion is constant between natural periods 0.16 *sec* and 0.5 *sec*, the maximum force ($F^{if}_{el,\max}$) that will be experienced by the infilled frame if it were to remain elastic, is the same as that of the bare frame ($F^{if}_{el,\max}$=3000 *kN*).

Thus, the ductility reduction factor required of the infilled frame is

$$R^{if}_\mu = F^{if}_{el,\max} \big/ P^{if}_y = 3000/1200 = 2.5. \tag{6}$$

Using this value of R_{μ}^{if} of the infilled frame and its natural period (T^{if}), the ductility demand μ_{demand}^{if} on the infilled frame from the DRF spectra given in Fig.3 is about 5. Hence, the maximum displacement experienced by the infilled frame is simply

$$\Delta_{\max}^{if} = \Delta_{y}^{if} \times \mu_{demand}^{if} = 0.8 \times 5 = 4.0\ mm. \tag{7}$$

The advantage of infills in the frame is now obvious. As against maximum bare frame displacement of 20 *mm*, the infilled frame undergoes maximum displacement of 4 *mm* only. This also means that at 4 *mm* displacement, even though the infills have cracked, the frame members (beams and columns) are still nearly elastic. This is because the ductility demand on them is

$$\mu_{demand}^{bf} = \Delta_{\max}^{if} \Big/ \Delta_{y}^{bf} = 4.0/4.0 = 1.0. \tag{8}$$

SUMMARY

Although the infilled frame loses strength and stiffness on cracking of the masonry infills, the initial stiffness and strength contributions of the infills significantly alter the overall behaviour of the frame. The presence of infills significantly reduces the maximum displacement and member ductility demand. This may explain the fact that many low-rise R. C. frame buildings with brick or stone infills and built without formal engineering design have withstood strong earthquake shaking in past earthquakes (*e.g.*, Uttarkashi, 1991, earthquake in India; Jain *et al.* 1992). There is a clear need for further research on this issue. Of course the masonry infills do cause their own problems: *e.g.*, short column effect in columns due to partial infills and torsional effect due to unsymmetric and random placement of infills.

REFERENCES

Brokken, S. T. and V. V. Bertero (1981). Studies on Effects of Infills in Seismic Resistant R/C Construction. *EERC Report UCB/EERC-81/12*, UC Berkeley, USA.

Gergely, P., R. N. White and K. M. Mosalam (1994). Evaluation and Modeling of Infilled Frames. *Proc. NCEER Workshop on Seismic Response of Masonry Infills, NCEER Report 94-0004.*

Jain, S. K., R. P. Singh, V. K. Gupta and A. Nagar (1992). Garhwal Earthquake of Oct.20, 1991. *EERI Newsletter, 26(2).*

Jain, S. K. and S. Das (1993). Analysis of Strong Motion Records from Uttarkashi Earthquake for Assessment of Code Provisions for Different Seismic Zones. *Earthquake Spectra, 9(4),* 739-754.

Jain, S. K., V. K. Saraf and B. Mehrotra (1995). Experimental Evaluation of Fundamental period of RC Frame Buildings with Brick Infills. *J. Structural Engineering*, SERC, Madras, India (under publication).

Klinger, R. E. and V. V. Bertero (1976). Infilled Frames in Earthquake Resistant Construction. *EERC Report UCB/EERC-76/32,* UC Berkeley, USA.

Kwan, K. H., C. Q. Lo and T. C. Liauw (1990). Large-scale Model Tests and Plastic Analysis of Multibay Infilled Frames. *Proc. Institution of Civil Engineers, Part 2, 89,* 261-277.

Liauw, T. C. (1979). Tests on Multistorey Infilled Frames Subjected to Dynamic Loading. *J. American Concrete Institute, 76-26,* 551-563.

Nagar, A. (1995). Modeling Seismic Response of Unreinforced Masonry Infilled Reinforced Concrete Moment-Resisting Frames. *Masters' Thesis,* Department of Civil Engineering, Indian Institute of Technology Kanpur, India.

Pires, F. and E. C. Carvalho (1992). The Behaviour of Infilled Reinforced Concrete Frames Under Horizontal Cyclic Loading. *Proc. 10 WCEE, Madrid, Spain, 6,* 3419-3422.

Riddel, R., P. Hidalgo and E. Cruz (1989). Response Modification Factors for Earthquake Resistant Design of Short Period Buildings. *Earthquake Spectra, 5(3),* 571-590.