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TECHNICAL RECOMMENDATION

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SUPPLEMENT TO P21 : AN EVALUATION METHOD OF P21 TEST RESULTS FOR USE WITH NZS 3604 : 1990

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REFERENCE

King A.B. and Lim, K.Y.S 1991. Supplement to P21 : an evaluation method of P21 tests results for use with NZS 3604 : 1990. Building Research Association of New Zealand Report. Judgeford.

1 INTRODUCTION

This document is published as a supplement to the 1988 edition of BRANZ P21 "A Wall Bracing Test and Evaluation Procedure". It provides a method of determining the bracing rating of wall systems at a level consistent with that stipulated within the 1990 edition of NZS 3604.

The method of testing is unaltered from that detailed in the 1988 edition of the P21 publication. The revised evaluation method can usually be applied to historic test data as well as to new data. Care is required during the interpretation of historic data, and it is recommended that this re-evaluation be undertaken by the original testing agency.

Work is currently underway at the University of Canterbury to determine a method of test based upon load control (rather than the current displacement control methods currently employed). It is expected that this will culminate in a revision to the method of test in due course.

2 BACKGROUND

NZS 3604 "A Code of Practice for Light Timber Framed Buildings Not Requiring Specific Design" was fully revised during 1990 and resulted in the publication of the 1990 edition late during that year. One major change incorporated within the 1990 edition, was the change of the code from being one based upon working stress design (WSD) principles, to one based on limit state design (LSD) concepts. This was necessary to maintain compatibility with the proposed New Zealand Building Code and with other structural codes which are also being revised into limit state format and will be published as such over the next few years.

WSD editions of NZS 3604 determined the number of bracing units required based upon actions which included appropriate reduction factors. The earlier editions of the P21 method of test established the number of bracing units available (i.e. the resistance to lateral loads) assessed at deflection levels which roughly coincided with deformations at which conventional wall systems began to experience damage.

Limit state codes require that the performance of buildings be considered at two limit states namely:

a) during normal operating conditions it is required to remain functional. This condition is known as a serviceability limit state,

b) during extreme load conditions it is required to possess sufficient strength that it will not collapse and will remain stable. This condition is known as the ultimate limit state.

NZS 3604:1990 determines the number of bracing units required to be resisted by buildings in order to satisfy their ultimate limit state requirements. These will typically be 30 to 50 percent greater than those detailed in WSD editions. This document details how to determine the compatible bracing rating of wall panels tested in accordance with the test regime detailed within the 1988 edition of BRANZ P21 method of test. Such bracing ratings are evaluated primarily from the ultimate capacity of the system, although the performance at the serviceability limit state is also assessed and may control the bracing rating in some instances.

The existing relationship between load and bracing rating remains unaltered with 20 Bracing units equal to one kilo Newton. (20 BU = 1 kN).

3 THE RELATIONSHIP BETWEEN NZS 3604 AND P21.

The level of load which buildings must withstand is stated in the bracing tables of NZS 3604. Entry into these table is by consideration of the earthquake and wind zone appropriate for the site, and from the geometry and fabric of the particular structure. The total number of bracing units required for each loading condition in each direction, results. It is possible to relate these bracing units to the load by using the conversion factor of 20 Bracing Units = 1 kilo Newton force (1 kN).

The designer is required to demonstrate that the structure has sufficient resistance to these loads by determining the number of bracing units provided by the particular wall layout being considered. This is accomplished by considering the length of the wall panels available, and the bracing rating per metre of the wall system being constructed, determining the number of bracing units available. Provided the number of bracing units available exceeds that required, the structure is deemed to be satisfactory, otherwise either additional bracing panels are required, or the construction form of the walls will require to be changed to one with a superior bracing rating. Bracing ratings are (conservatively) available through Table K1 within NZS 3604, or more reliable results may be determined by physical testing within the laboratory and thus supplied by the manufacturer.

NZS 3604:1990 stipulates the level of load applied at the ultimate limit state and this supplement provides the compatible means of resistance at the capacity of the panel for the loading condition under consideration. Previous editions of NZS 3604:1984 stipulated the level of load applied from working stress design requirements. Likewise earlier editions of P21 derived a compatible set of resistance ratings based on the resistance available at serviceability levels.

4 ULTIMATE AND SERVICEABILITY LOADS

(Note these have been derived from DZ 4203:1991 dated 12.11.91 and references relate to that document).

4.1 Earthquake Loads

Assuming that the structure is analysed using the equivalent static method, the horizontal shear force at the base of a structure at the ultimate and serviceability limit states respectively are:

$$Q_s = C_b(T_1, 1)\ L_s R\ Z\ Wt \text{ from Equation 4.6.1}$$

$$Q_u = C_b(T_1, \mu)\ L_u R\ Z\ Wt \text{ from Equation 4.6.2}$$

where $C_b(T_1, 1)$ = basic seismic acceleration coefficient for a structure of period T_1, with a structural ductility factor of 1;

$C_b(T_1, \mu)$ = basic seismic acceleration coefficient for a structure of period T_1, with a structural ductility factor of μ;

T_1 = fundamental period of the structure, assumed = 0.4 for houses;
L_s = the limit state factor at serviceability = 0.167 from Table 4.6.4;
L_u = the limit state factor at ultimate = 1.0 from Table 4.6.4;
Z = Zone factor (obtained from Fig 2.2 in NZS 3604)
Wt = Seismic weight of building
R = Risk factor for structure = 1.0 for Category IV structures from Table 4.6.3

Then

$$Q_s/Q_u = \frac{C_b(0.4,\ 1) \times 0.167 * Z * Wt}{C_b(0.4,\ \mu) \times 1.0 \quad * Z * Wt}$$

$$= \frac{C_b(0.4,\ 1) * C(0.4,\ 4) * 0.167}{C_b(0.4,\ 4) * C(0.4,\ \mu)}$$

= (0.80/0.28) * K_4 * 0.167 from DZ 4203 assuming normal soil

= 0.48 * K_4

where: $K_4 = \dfrac{C_b(0.4,\ 4)}{C_b(0.4,\ \mu)}$ = the ductility modification factor, being the ratio of the actual seismic coefficient at ductility μ to the 3604 ductility factor which was taken as equal 4 in the derivation of the design loads.

Therefore Ratio of $\dfrac{\text{Seismic coefficient(serviceability)}}{\text{Seismic coefficient(ultimate)}}$ = 0.48 K_4

4.2 Wind Loads

The ratio of the serviceability to limit state wind speed;

V_s/V_u = 0.75 for most regions. (DZ 4203 Section 5.4.3)

As the wind force is given by (Equation 5.5.1)

$$W_s = 0.6 * V_s * V_s$$

and

$$W_u = 0.6 * V_u * V_u$$

Then the ratio W_s/W_u = 0.75 * 0.75 = 0.563.

Where W_u = wind force associated with the ultimate limit state (kN)
W_s = wind force associated with the serviceability limit state (kN)

5.0 PERFORMANCE OF WALL PANELS

5.1 General

A sample evaluation form for wall panel tests is provided in Figure 1. The background for the parameters used in the form is discussed below.

For simplicity all bracing requirements within NZS 3604:1990 relate to the loads applied at ultimate limit state conditions. No reference is made to the load levels associated with satisfying serviceability limit state conditions. One means of overcoming this deficiency is to down rate the wall bracing rating (the nett effect of which is to increase the lengths of bracing walls required) when:

$$\frac{\text{serviceability resistance}}{\text{ultimate resistance}} < \frac{\text{serviceability load}}{\text{ultimate load}}$$

However the RHS of this equation has been derived above

= 0.563 for wind

= 0.48 K_4 for earthquake

Thus when Serviceability load governs

Then ...... bracing rating = $\dfrac{\text{serviceability resistance} * 20}{0.56 \text{ (wind) or } 0.48 * K_4 \text{ (earthquake)}}$

5.2 Earthquake Resistance

5.2.1 Earthquake resistance at Ultimate Limit States

The ultimate resistance of the wall to earthquake loads, factored so that it represents an equivalent $\mu = 4$ elastoplastic load, is given by :-

$$R_{qu} = K_4 * R \text{ kN}$$

Where R = the mean of the residual loads (in kN) (the mean is assessed from the residual load from both the +ve and -ve cycles for all three tests i.e., 6 values - refer Figure 2)

K_4 = the ductility modification factor

$$= \frac{C_b(0.4,4)}{C_b(0.4,\mu)} \quad \text{(as defined in Section 4.1)}$$

Where μ = average structural displacement ductility factor

$= y/d \leq 4.0$

where y = the average failure or peak deflection of the three tests;

d = the average first cycle displacement at half peak load.

A major difficulty lies in the determination of the equivalent "yield point" displacement for degrading systems such as those associated with timber framed members which rely heavily on the performance of the metal fasteners for their ductility. Park (1989) discussed four alternative methods of defining the yield displacement which were applicable to concrete structures as shown in Figure 3. These have proved difficult to translate to degrading timber systems (Dean et al, 1986) and the above simplified approach has been adopted as an interim measure while further investigation is continuing in an attempt to define the equivalent elasto-plastic system which demonstrates performance characteristics similar to those encountered during testing.

For consistency of application, where panels resist loading in an asymmetric manner, application of load should be in the weakest direction for the first load cycle, thereby ensuring a non-conservative assessment of the "equivalent yield" displacement point.

Thus when the ULTIMATE LIMIT STATE CONDITIONS CONTROL (Ref section 5.1) then the Bracing rating for the panel is given by:

$$BU_{qu} = 20 * K_4 * R$$

5.2.2 Earthquake resistance at the Serviceability Limit State

The resistance of the wall for serviceability limit state conditions is given by:-

$$R_{qs} = K_1 * S \quad \text{kN}$$

where R_{qs} = Resistance (earthquake - serviceability limit state)
S = the mean of the loads (kN) at a deflection of X, DLW or DLQ mm as appropriate in each direction;
K_1 = $1 - C/X$ where $0.8 < K_1 < 1.0$ is the modification factor for non-recovery of displacement during the serviceability displacement loading cycles (i.e., X, DLQ or DLW);
C = the residual displacement after cycling to X, DLW or DLQ;
X = wall height/300 = 8 mm for a 2.4 m high wall;
DLW = the selected deflection limit for wind forces;
DLQ = the selected deflection limit for earthquake forces;
(See sections 5.1 of P21 for definitions of DLW and DLQ)

When the SERVICEABILITY CONDITION CONTROL (ref section 5.1)

Then the earthquake bracing rating of the system is

$$BU_{qs} = \frac{R_{qs} * 20}{0.48 * K_4} \qquad \frac{(= 20 * K_1 * S \quad)}{0.48 * K_4}$$

5.3 Wind Resistance

5.3.1 Wind resistance at Ultimate Limit states

The ultimate resistance of the wall to wind loads is given by :-

$W_u = 0.9\ P$ kN

Where P = the average peak loads (kN) (average maximum positive and negative loads for three specimens - i.e., 6 values - ref Figure 2).

The factor of 0.9 is introduced as an allowance for some degradation that will occur under repeated loading such as will occur because of turbulence effects during extreme wind loads.

When the ULTIMATE LIMIT STATE CONDITION CONTROLS

Then $BU_{wind} = 20 * W_u \quad (= 20 * 0.9 * P)$

5.3.2 Wind Resistance at Serviceability Limit State

The wind resistance available at the serviceability limit state, W_s, is determined from

$$W_s = K_1 * S \text{ kN}$$

where W_s = Serviceability wind resistance
K_1 = displacement recovery factor
S = average load (resistance) applied at displacement X

When SERVICEABILITY LIMIT STATE CONDITIONS CONTROL (ref section 5.1),

$$\text{Then } BU_{wind} = \frac{W_s * 20}{0.563} \qquad \left(= \frac{20 * K_1 * S}{0.563} \right)$$

6 MODIFICATION FACTORS

6.1 General

Previous editions of P21 required that the loads derived from the test be modified by various K factors which reduced the level of load at which the bracing rating evaluation was carried out. The changes included in this edition eliminates the need for such modification factors at the Ultimate limit state, although the 'recovery' modification factor (K_1) is still applied to serviceability loads as discussed below and defined in Section 5.2.2.

6.2 Displacement Recovery Factors (K_1)

The factor K_1 specified in P21 is applied to allow for any inelastic behaviour (non-recovery) of displacement during the serviceability loading cycles. In particular, if K_1 is less than 0.8, the wall shall be rated as unacceptable. The reason for this is that under serviceability loading, a predominantly elastic behaviour is preferred thereby minimising permanent offsets at this level of load. A modest amount of inelastic behaviour is permitted by the present rules. This logic still applies and it is appropriate that K_1 be considered and applied when assessing the serviceability load.

6.3 Repeated Load Factor (K_2)

The factor K_2 applied to allow for resistance to repeated loading can be disregarded because the ultimate strength of the wall under earthquake load is based on the residual strength value. It is therefore of little significance if the load under cyclic loading degrades such that K_2 is less than 0.8, as recommended in P21, i.e., a 50% degradation in load at the fourth cycle compared to the first cycle. Moreover, in situations where the ductility of the wall is less than 4, the ultimate resistance of the wall shall be obtained by including a ductility modification factor (K_4) in the evaluation since NZS 3604 assumes a wall ductility of 4 in deriving the earthquake loads.

6.4 Reserve Strength Factor (K_3)

The factor K_3 applied to allow for lack of reserve strength can be neglected since the revised method of interpretation is applied to the residual load only, thereby incorporating the effect of this factor.

6.5 Asymmetry of Performance

It is considered appropriate that the "Asymmetry of performance" criterion specified in previous editions of P21 should remain. This stated that where an asymmetric performance of a panel is experienced, variations in load should not vary by more than 20% for that loading cycle. Where variations are greater, the upper load shall be reduced to 1.2 times the lesser load when assessing the panel performance.

Where an asymmetric performance does occur, the initial cycle should be in the weakest direction, thereby ensuring that the most severe reduction is applied with regard the ductility modification factor (K_4).

6.6 Extrapolation of Results with Length

Narrow panels are dominated by flexural distortion when subjected to lateral loading, while squat panels are dominated by shear distortion. In order that the test mode is maintained in practice, the bracing rating determined from a given series of test panels, may only be applied to like panels of the length of those tested and up to twice the test panel length.

7.0 REFERENCES

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	Servicability Cycles Cycle To Displacement X= (mm)		Ultimate Cycles Cycle To Displacement y = (mm)			
Specimen No.	Load S (kN)	Residual Displacement C (mm)	Maximum Load P(kN)	Calculated P/2(kN)	Displacement @P/2 = d (mm)	4th Cycle Load at y mm R (kN)
1	+ -	+ -	+ -	+		+ -
2	+ -	+ -	+ -	+		+ -
3	+ -	+ -	+ -	+		+ -
Averages	S=	C=	P=		d=	R=

K1 = 1.4 - C/X = Where 0.8 < K1 < 1 and X = 8mm or DLQ or DLW

If K1 < 0.8 the result is to be ignored.

F = K1 x S =

The "Asymmetry Of Performance" criterion in the last paragraph of Section 6.5 shall be followed.

u = y/d =

u	1.00	2.00	2.50	3.00	3.50	4.00
K4	0.35	0.60	0.67	0.74	0.87	1.00

For other values of u, linear interpolation is used to determine K4

Therefore K4 =

EVALUATION : EARTHQUAKE PERFORMANCE

BU(EQ) = 20 x the lesser of K4 x R or F / (K4 * 0.48)

K4 x R = F / (K4 * 0.48) = Therefore BU(EQ) = 20 x

BU(EQ) **=** **Bracing Units**

EVALUATION : WIND PERFORMANCE

BU(wind) = 20 x the lesser of 0.9 x P or F/0.563

0.9 x P = F/0.563 = Therefore BU(WIND) = 20 x

BU(WIND) **=** **Bracing Units**

Figure 1 Sample Test Data Evaluation Form

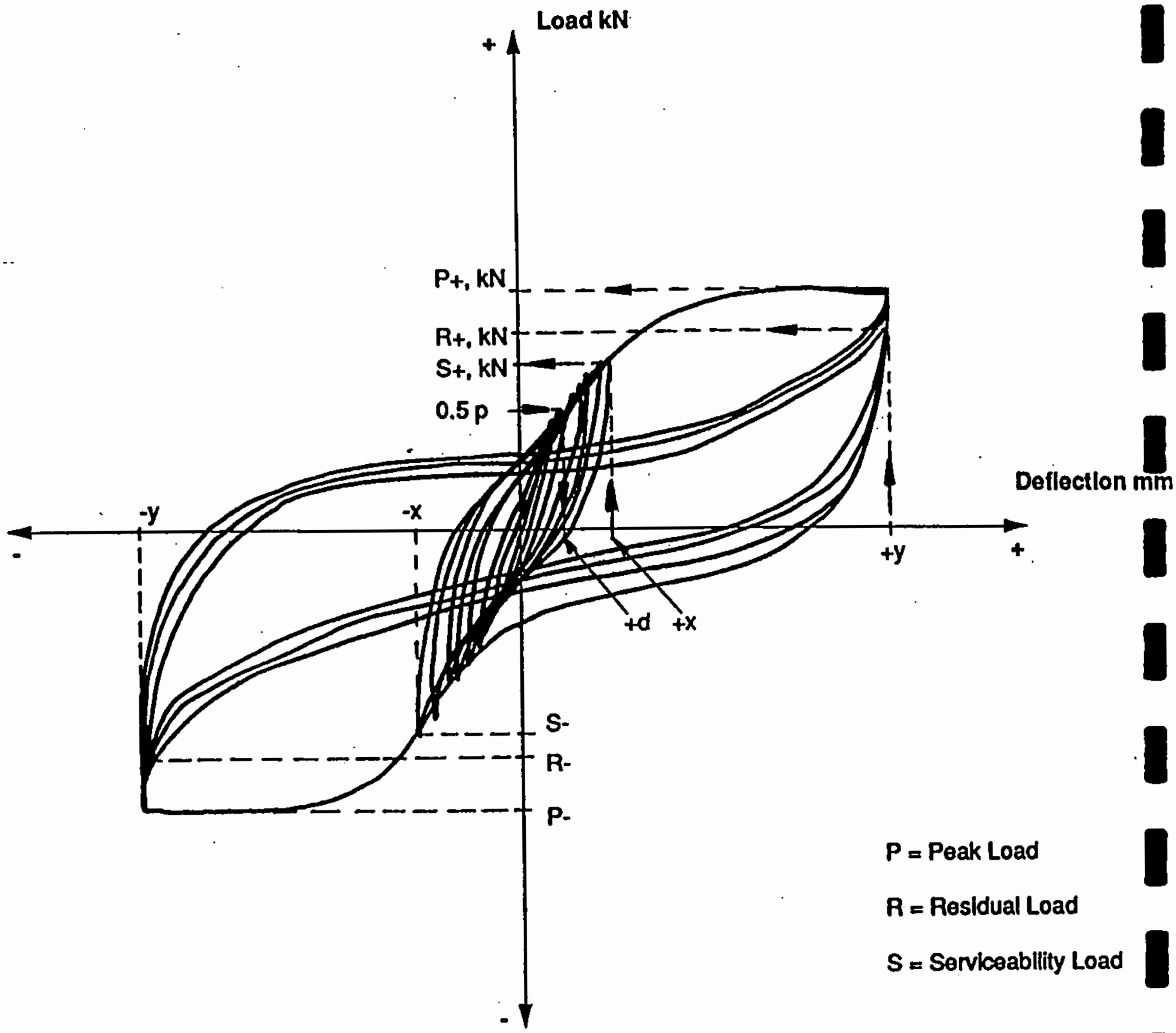

Figure 2: Typical P21 Test Plot

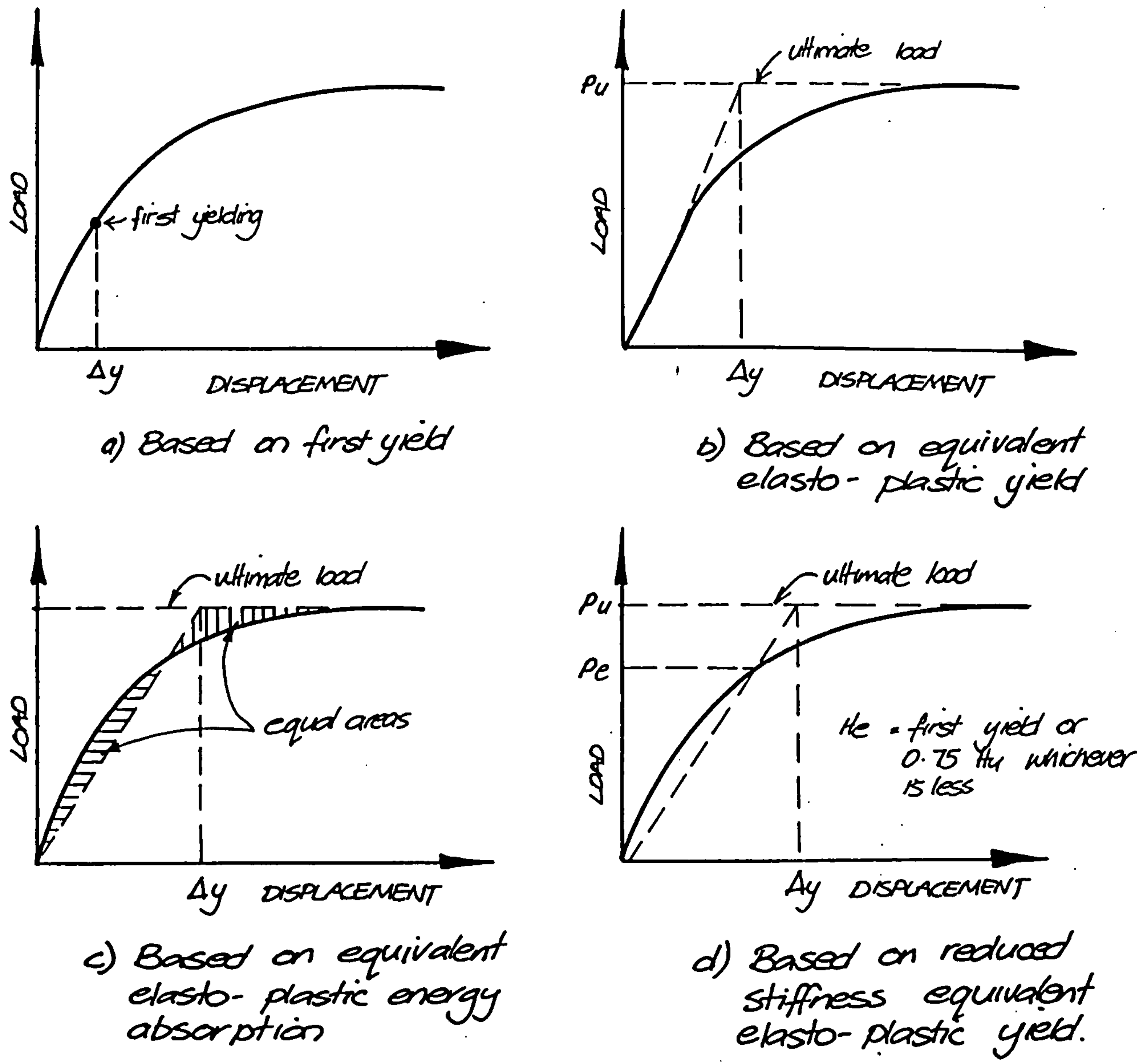

Figure 3: Alternative definitions for yield displacement (from Park 1989)

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