Design, Specification, Manufacture and Testing of Laminated Elastomeric and Pot Bearings to AS5100.4

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SYNOPSIS

The Australian Bridge Design Code is about to be re-published as Australian Standard AS 5100. This paper provides some notes for bridge designers on the specification of bearings to Part 4 of this Standard, "Bearings and Deck Joints" AS5100.4, and compares it with its forerunners, ABDC ('92/96 "Austroads Bridge Design Code, Part 4") and AS1523 "Elastomeric Bearings for Use in Structures", as well as other international codes.

We concentrate on the following differences between AS5100.4 and ABDC:-

a) Pot bearings and sliding surfaces are now specified at the more logical ultimate limit state (ULS), with a new set of design criteria and generally more conservative stresses.
b) Laminated elastomeric (LE) bearings are still specified at the serviceability limit state (SLS), but with tighter limits for shear and rotation.
c) Anchorage requirements for both pot bearings and elastomeric bearings are amended, again slightly more conservative.
d) Reaction to sliding of bearings has been rationalised (for the effect on the structure).
e) Guidance for uplift is provided.
f) Testing provisions have been clarified for elastomer, for LE's, and for pot bearings.

Although we discuss some clauses in AS5100.4, this is not an official commentary. The authors represent Ludowici Ltd, an Australian designer and manufacturer of elastomeric, pot bearings, and other engineered products (joints etc), whether for bridges, buildings, earthquake, or vibration isolation. It is from this perspective that we discuss the need for a clear understanding between all team members involved in the design and manufacture of the bridge (or building) and its critical components. The use of testing is discussed in detail, whether to "prove" designs of pot bearings, or for the quality control of LE bearings.

Essential design parameters and their "permissible interaction" are discussed. We emphasise the information that must be transferred from the bridge designer to the bearing designer to permit an economical and adequate design of bearings. An example of a detailed Bearing Questionnaire is given, and some design rules additional to AS5100.4 are also suggested.

1.00 INTRODUCTION

As at date of writing, Australian Standard AS5100.4 (ref 1) is finalised and ready for imminent release. This standard will significantly amend the rules for the design and specification of bearings when compared with the previous Australian codes, ABDC (ref 2), and AS1523 (ref 3), largely driven by trends in overseas codes, in particular in Europe, EN1337 (ref 5-6) and USA, AASHTO LRFD (ref 7). It is relevant that many of these new rules make for more conservative designs than ABDC, both for pot bearings and LE bearings, as will be explained. We discuss Bearing Performance Schedules and design parameters which must be transferred from the bridge designer to the bearing designer to permit an economical and adequate design of bearings, as well as their attachments and their testing.

Most modern bearings fall into one of two main classifications, namely

- Elastomeric, viz laminated elastomeric bearings (LE), plain pads or bearing strips; or
- Pot bearings, with or without sliding contact surfaces, possibly subject to uplift.

Another classification, 'Mechanical bearings' (rockers, etc), is also given in AS5100.4, but ignored here as largely out of date, or more applicable to the rating of existing bridges.

Notation and Abbreviations used in this paper include the following:-

- SLS = Serviceability limit state
- ULS = Ultimate limit state (factored)
- LE = Laminated elastomeric bearings
- LF = Load Factor
- N and N* = compressive load on a bearing, SLS and ULS resp (Note, previously assumed to be vertical, and referred to as 'V' in ABDC and BS5400(4))
- H and H* = shear load on a bearing, SLS and ULS resp (referred to as 'V' throughout EN1337 and in AS5100.6 etc. Due to this potential confusion, 'V' is not used here).
- α and α* = rotation on a bearing, SLS and ULS resp.
- α*DL and α*LL = rotation due to DL (permanent, irreversible) and LL (reversible).
- α.S = earthquake factors
- μc = effective friction factor at the contact rim (vertical) between pot and piston

For friction at a PTFE sliding surface (effect on the structure):-

- NPE = the SLS permanent load = NDL
- σ = pressure on the PTFE
- μ = characteristic friction factor at NPE
- μr & μa =relieving and adverse friction
- H*fr = the friction at the PTFE slideface = LF . μ . NPE

Minimum Compression loads and frictional assistance for anchorage design (and testing):-

- Nmin = the minimum concurrent load normal to the bearing anchorage interface, SLS - particularly for anchorage design of LE brgs, or possibly SLS uplift for pot brgs.
- N*min (or N*min coex) = the factored ULS value of Nmin, usually coexistent with H*, particularly for anchorage design of pots (and for the testing thereof).
- (ϕ .μkmin . N*min) = frictional assistance for anchorage of pots (where permitted)

Maximum Compression load for "best economy" design (and testing):-

- N*max = the maximum load, ULS, whether or not shear load is acting.
- N*max coex = the maximum concurrent load, ULS (particularly for "best economy" design and/or testing of pots). If not given, this must be assumed to be N*max.

Rated (Compression) Capacity and other parameters for LE bearings. Note that we speak of shear and rotation "IN the span or longitudinal direction", not "ABOUT" the transverse axis.:-

- Roo = Rated capacity at zero rotation and zero shear
- Ros = Rated capacity at zero rotation and maximum shear, for the axis in question
- Rro = Rated capacity at maximum rotation and zero shear, ditto
- Rrs = Rated capacity at maximum rotation and maximum shear, ditto
- R,0.01r,#124 = Range of rated capacity at (e.g.), 0.01 rads and +/-124mm shear, ditto
- (αlon / N) = the "longitudinal rotation rate" for an LE, (measured in rads / kN), ditto.

2.00 POT BEARINGS

2.01 POT BEARINGS, ULTIMATE LIMIT STATE APPROACH

For pot bearings, AS5100.4 generally moves towards the (far more logical) Eurocode EN1337 ULS philosophies, and existing designs 'familiar' to Australian consultants will almost invariably have to be increased in (at least some) dimensions to take account of the new design stresses. The effect is most noticeable for high LL/DL ratios (hence high load factors).

Various checks for pot bearings are shown in Figs 1, discussed further below, including

- mean pressure on the elastomer, previously 40MPa SLS, now 50MPa ULS, (Fig 1a),
- thicknesses of pads for rotation, previously min of diameter/20, now De/15, (Fig 1b); also 15% strain at edge due to SLS rotation, now 20% strain due to ULS rotation,
- mean pressure on the PTFE, previously 45MPa SLS, now 50MPa ULS, (Fig 1a),
- peak pressure on the PTFE, previously 55MPa SLS, now 60MPa ULS, (Fig 1a and 2),
- anchorage bolts and dowels, (Fig 1c),
- the pot wall, the contact rim, (Fig 1d), and uplift as applicable,
- mortar interface pressures (here, very little detail is given in AS5100.4), (Fig 1d)

The distribution of pressure through steel is given as 60deg in BS5400, and 45 to 60deg in prEN1337; but is unspecified in AS5100.4. Concrete pressure rules are given in AS5100.5, but reinforcement is a factor. The writers STRONGLY recommends that Schedules (Fig 3, para 2.09) require - and design submissions confirm, para 2.10 - that :-

- mean contact pressures be checked at the mortar interface,
- be based on a distribution angle of 60deg to the vertical, and
- be limited to 30MPa ULS, provided that the bearing is less that 2/3 the pier width.

This is FREQUENTLY the most critical parameter, especially for European designs which tend to omit attachment plates.

2.02 COMPARISON WITH '92/96 ABDC – MIXTURE OF SLS AND ULS FOR POTS

It is worth noting that the previous code ABDC presented difficulties in that pot bearings were to be designed to SLS loads, and yet many load cases (and checks) could only be given (or carried out) at ULS. With AS5100.4, it is much easier to take account of the likes of:-

- Earthquake loads, which are only usually available at ULS.
- Minimum lateral restraint requirements, which were / are only given in ULS terms.
- The maximum bearing on interfaces with sub-and superstructures, which could only be checked against Part 5 ULS loads (unless of course a limiting value is specified).
- And the important matter of bolt strengths, which were also only available at ULS.

The new ULS philosophy of AS5100.4 is much more consistent and logical.

2.03 POT BEARINGS – REPRESENTATIVE TESTING, AS5100.4.

AS5100.4 requires representative bearings to be testloaded to the ULS loads and rotations, and (unlike some other codes such as BS5400), the bearings shall remain undamaged after this ULS testing. Tests represent a major part of "QA design validation" to ISO9001-2000. Incidentally, this latter code "cancels and replaces" ISO9001-1994 (Design and Manufacture) and ISO9002-1994 (Manufacture only), so that only in the fine print of the Scope of Accreditation can the inclusion of the "design element" be ascertained.

AS5100.4 (CL 13.2) requires ULS tests as follows:-

- Compression N*max (times 1.0, typical for all tests, unless noted otherwise)
- Shear at N*max H*max together with N*max coex
- Shear at N*min H*max together with N*min coex
- Rotation 0.7 x N*max with the ULS rotation, α*max,

Acceptance Criterion, "no damage which will affect their durability".

Note that Specifications written around AS5100.4 should also address the question of test frequency, which is not defined. Many Australian State specifications currently require "one in each ten or part thereof of each bearing design". A "bearing design" should be specified as any unique design, although different slide plate lengths need not all be tested, provided that it can be shown that the tested slideplate represents all (least bolts per unit length of guide, etc).

It is also worth noting that neither BS5400 nor AS5100.4 insist on friction tests. BS5400(4) explains that short term lubricated friction tests will "always" pass with a healthy reserve. The writers agree, but recommend, in the interests of long term performance, that Specifications require that polished Gr 316 stainless steel sheets be used, i.e. type 2B (as-rolled) PLUS an additional process "polished to a mirror finish using automated machinery". Such sheets are usually then protected by adhesive plastic. AS5100.4 requires "polished type 2B as-rolled to 0.4μm CLA". The important point here is the "MIRROR" polish (Fig 12b) rather than the roughness, 0.4μm, which is easily achieved. Type 2B sheets pass through polished rollers, and generally have a consistent roughness (better than 0.2μm), but the sheet is not otherwise polished in any way. Mechanical polishing is recommended to remove the microscopic grit from the stainless surface which otherwise becomes lodged in the PTFE, discolouring it, and having a major effect on the long term wear of the PTFE and its long term friction (Ref 10).

2.04 POT BEARINGS – PREQUALIFICATION TESTING, EN1337.

It is also worth noting that the prEN1337-5 has tight requirements with respect to prequalification testing. These include:-

- wear tests on the elastomer seal, where a piston is tilted back and forward until a distance of around 500m to 2000m is accumulated at the cylinder contact rim, albeit only 3mm or 4mm per cycle,
- extensive rotational stiffness tests, separating the effects of long term and short term rotations, α*DL and α*LL (effectively increasing a bearing's rotation capacity); and
- long term friction tests, (arguably unnecessary provided that the stainless steel and PTFE are specified correctly).

In this respect EN1337 is more stringent that AS5100.4, and written around the extensive prequalification procedures (prior to production) as practiced in Germany for some years.

2.05 ANCHORAGE OF POT BEARINGS – ATTACHMENT BOLTS and DOWELS

AS5100.4 reinforces the requirement that (except for incrementally launched bridges under certain circumstances), pot bearings must be anchored by a combination of friction assistance (due to gravity) and mechanical anchorage, even though friction alone may be sufficient.

The frictional assistance, (ϕ .μkmin. N*min), in AS5100.4 is 60%-90% of the EN1337 value, and should be ignored altogether for "highly dynamic structures", e.g. where the product of the Acceleration Coefficient and the Site Factor αS as defined in Part 2 of the Standard exceeds 0.2. (Of course frictional "assistance" due to 8.8(TF) bolts is still acceptable, Fig 12a).

High load fluctuations on railway bridges may also warrant discounted frictional assistance under (and above) bearings. In determining the minimum compressive load N*min on a bearing, the permanent effects shall take into account a rebound force based on the Dynamic Load Allowance, DLA, and reduced accordingly. In this respect the minimum load N*min would normally be less than the factored ULS Dead Load (in addition to the sub-unity load factor of 0.85 incidentally). The value of N*min (or N*min coex) should be included in the Bearing Schedule (Fig 3a).

Attachment bolts would not normally be tested, and calculations by the bearing designer should arguably be submitted for their design, including the effect of an eccentric bolt group at limit of movement of a slide plate, (Fig 1c).

2.06 POT BEARINGS, RUBBER PRESSURES

The design pressures on the elastomer are more stringent, roughly based on prEN1337-5. The design pressures of the elastomer vary as follows (roughly sorted). In order to compare SLS limits and ULS limits, we have assumed a mean effective Load Factor of 1.5 (although it is recognised that this could well be higher, e.g 1.6, with the new massive live loads):-

• BS5400 & ABDC	mean pressure 40Mpa SLS	or nom 40x1.5 = 60Mpa ULS
• **AS5100.4**	**nom 33.4 Mpa**	**50 Mpa**
• PrEN1337-5	nom 30 Mpa or 33.4MPa	46 or 50Mpa, (ϕ = 1.3 or 1.2 resp)
• AASHTO	25Mpa	nom 37.5 MPa

Example. A pot bearing previously capable of say 10000kN SLS (using 40Mpa SLS pressure on a 634mm diameter pad) is now capable of only 12500kN ULS (say 12500/1.5 = 8340kN SLS, or even 12500/1.6=7810kN SLS) when the rating is adjusted for 50Mpa ULS, same pad.

A minimum of two split sealing rings are required for this pad, (an important requirement to limit rubber extrusion).

2.07 INTERNAL FORCES AND MOMENTS WITHIN POTS

AS5100.4 does not pretend to be an exhaustive 'design manual for bearing manufacturers', but relies more on the fact that representative bearings must be tested to the full ULS load. The ring (hoop) of the pot bearing should be designed and tested for the worst combination of (maximum) compression and shear force (Fig 1d).

The commentary gives some guidance on the rotational moment due to the rubber pad, and refers one to the concepts of EN1337 to calculate the other moments on the PTFE. These can include shear loads, and "vertical friction" at the contact rim due to these loads (Fig 2).
A free-sliding multi-movement bearing potentially has loads and moments as follows :-

- compression N*, and the "rubber rotation moment", M1, or N*.e1; (e1 = eccentricity);
- shear (in this case PTFE friction, Hfr, times its lever arm, hHfr), M4, (eccy = e4); and
- the friction at the piston/cylinder contact rim, M5, (eccy = e5). In this case, a vertical friction of 20% of the shear force is assumed with a lever arm of the internal radius of the pot. Note that 20% includes a "combination factor" as well as a friction factor.

A guided bearing has all of the above plus moments due to :-

- the external shear on the guide, H*max, M2, (eccy= e2); and
- the friction at the contact rim due to this, 0.20 H*max, M3, (eccy = e3).

The eccentricities, e1 to e5 as applicable, can then be vector summed (Fig 2a).

These forces and moments create an eccentric compression on the PTFE (and mortar etc, ref 8), and notes are included in AS5100.4 on the effective peak pressure using a uniform stress block. This stressblock should be chosen to have the same centre as the eccentricity of the compression force on the PTFE when all coexistent moments are taken into account. The option of a linear stressblock, (P/A + M/z), is also given, but is generally more conservative.

2.08 POT BEARINGS SUBJECT TO UPLIFT

The introduction of SM1600 traffic loading will result in an increased incidence of uplift at bearings in bridges. AS5100.4 strongly recommends that, wherever possible, uplift bearings be avoided, and uplift be taken "elsewhere". However it does permit uplift in pot bearings if essential, and, in this respect, differs from EN1337, which does not cater for uplift at all.

According to AS5100.4 it is important to differentiate between uplift at SLS and at ULS. It is also important to differentiate between "compatibility" uplift and "equilibrium" uplift. Should a bearing fail in the former, then loads are redistributed, and can be checked / modelled as a "loss of support". The question then is "does the structure become unstable?". If yes, then the critical "equilibrium uplift" must be catered for. Considerably more detail is given in AS5100.4 and its commentary. Testing under uplift should be specified as necessary – a relatively expensive matter, considering that special jigs must be custom -made. Concurrent shear load is "difficult", and friction tests in uplift are virtually "impossible".

It should be obvious that uplift load cases are much more likely to lead to <u>catastrophic</u> failure than compression, and matters such as "dual" and "fallback" mechanisms are a wise precaution, as well as useful during maintenance. BEST of all, provide bearings both above and below the member in question, so that the force either up or down is in COMPRESSION.

As a related matter, a minimum compression is required to permit a guided bearing (made up of three plates) - as against a fixed bearing (made up of 2 plates) - to be stable under shear load. Occasionally bearings are specified with N*min less than 20% of the shear load (and sometimes as "nil"), and many catalogue bearings would become unstable under these circumstances. These could arguably be treated as uplift bearings, or "special" designs.

2.09 POT BEARINGS – BEARING PERFORMANCE SCHEDULE

A typical Schedule is set out in the Commentary to AS5100.4. Fig 3a adds further detail, including two "Load Combinations", and hence four Load Cases implied (N*max and N*min in each case – also Fig 3b.). Extra Load Cases may be justified eg for earthquake, transverse wind, etc, where these are unlikely to coexist with peak live load etc. Unless separately specified, load cases will become superimposed and totally unrealistic. Fig 3b becomes the enveloping "box". Yet that is the norm in many states. Also within a "Load Combination", Fig 3a suggests a clear statement of whether longitudinal and transverse effects coexist.

Concerning rotations, it is common that a value is given, say 0.012 rads, without further qualification. It may or may not be acceptable for the pot bearing designer to assume that rotation is ONLY in the span direction, (although this would be a common assumption for an LE designer for instance). If say 0.012 rads in ANY direction is required, then M1 in Fig 2a should also be in any direction. CLEAR Load Cases (even a clear statement of this worst case rotation scenario) are RARELY available to the bearing designer, and would help to minimise ambiguity (which is after all a QA requirement).

As a minimum, the schedule MUST give N*max, N*min, α*max, H*max, and δ*max, (these last two parameters in longitudinal (lon) and/or transverse (tra) directions as applicable). This would give the (very conservative) "enveloping box" option in Fig 3b.

In more detail, for designing (and testing) the rubber pad, PTFE and ring of the pot, we need:-

N*max, and α*max for the rubber pad; and the worst combination of

H*max (coex), N*max (coex), and α*max for the PTFE, ring, and testing.

For designing the anchorage bolts and dowels (Fig 1c), we need the worst combination of :-

H*max (coex), and N*min (coex), **plus permission to use frictional assistance,** e.g.

ϕ. μkmin = 0.30 for steel on concrete, 0.18 for most steel, or nil for extreme EQ etc.

For designing slide plates, we need:-

The ULS movement requirement, total capacity e.g. 2a, or +/- a

Or if necessary, (and permissible) a preset of say +p, making +(a-p), -(a+p)

Any uplift requirement must be clearly defined, both at SLS and ULS, including clear statements of simultaneous shear, rotations and movements, and whether these latter effects REMAIN STABLE or CHANGE during periods of uplift. Testing requirements in the case of uplift must also be clarified, since they are additional to AS5100.4 guidelines. Any fatigue requirements (incl design number of cycles and load range) must be clearly specified, particularly for tension or shear (Fig 12a) (but certainly tension)!.

The articulation of the structure, including layout, nomenclature and orientation of bearings, should be indicated in a diagram on the drawings. Preferred ranges of plan dimensions or heights should be given in sketches - also skews, tapers, and attachment preferences at bottom and top interfaces (sub-and superstructure) – whether attachment plates are required, and any required bolt centres (to suit precast girders), or minimum bolt sizes (eg minimum restraint).

Finally, any specific requirements should be given, abnormally aggressive conditions, (flood-prone, or marine or industrial for instance), electrical insulation requirements (some railway bridges), or movement-indicating scales, or load monitoring transducers fitted , etc.

2.10 DESIGN SUBMISSION HOLD POINT

Although not mentioned in AS5100.4, we would recommend a HOLD POINT for the submission of design details from the bearing designer / supplier. This should include :-

a. Name of the bearing supplier;
b. Confirmation of all load cases (axial & shear load, rotation and movement in each);
c. A drawing of the assembled bearing and plates to scale with overall dimensions;
d. Calculations by a Practicing Engineer (MIEAust) of the rubber pressure, the rubber thickness, the PTFE mean and peak pressures, max design pressure on sub- and superstructure and method of calculation thereof, the bolts and dowels, and sealing the gap between piston and upward facing cylinders for all rotations (eg silicone sealant);
e. Evidence of rubber seal-ring performance; and for rotational stiffness used in calcs;
f. PTFE thickness, dimpling pattern, grease type, and bonding details (as applic);
g. Confirmation of machine mirror polish and stainless st attachment (TIG suggested);
h. Treatment of skew and taper if applicable;
i. Surface protection types, colours, thicknesses, grit blast details;
j. Test loads, details and facilities (NATA as applicable);
k. Lifting arrangements; and finally
l. Any deviations from the drawings or specification.

3.00 SLIDING CONTACT SURFACES

3.01 MAX VALUE OF PEAK PRESSURE ON RECESSED PTFE

The following pressures apply to virgin PTFE dimpled, lubricated and contained in a recess (half its thickness). Arguably, Fig 2b, the PTFE should also be etched and epoxy bonded - relatively expensive - but this is only mentioned in AS5100.4 where there is risk of uplift.

- BS5400 or ABDC peak pressure 55Mpa SLS or nom 82.5Mpa ULS
- PrEN1337-5 nom 40 Mpa SLS 60 Mpa ULS**(uniform block)
- **AS5100.4 nom 40 Mpa SLS 60 Mpa ULS**(uniform block)**
- AASHTO nom 26.7Mpa SLS 40 Mpa ULS (linear stressblock)

** Just as in EN1337-2, in these cases, peak pressures may be calculated using a uniform stressblock (i.e. rectangular) on a reduced area, which depends on the eccentricity Fig 2a. The equivalent peak stress using a linear (P/A + M/z) stress block on the full area is higher, around 65 – 75Mpa ULS (very approx). Even this is a significant drop from nom 82.5Mpa ULS in ABDC (and BS5400). EN1337 relies almost "exclusively" on this check.

3.02 OTHER PRESSURE CHECKS ON RECESSED PTFE

Although not mentioned in EN1337-2, the mean pressure limit is still specified in AS5100.4:-

- BS5400 or ABDC mean pressure 45Mpa SLS or nom 67.5Mpa ULS
- **AS5100.4 nom 33.4 Mpa 50 Mpa**
- PrEN1337-5 no mention
- AASHTO nom 26.7Mpa 40 MPa

It should be noted however, that there is no longer a requirement to check the maximum pressure, mean or peak, at the SLS permanent load, i.e. for creep, (where ABDC permitted only 30MPa mean and 35MPa peak). The only code still requiring this is AASHTO LRFD.

3.03 FRICTION AT RECESSED PTFE SURFACES

Friction factors are explained in some detail in EN1337-2 and AASHTO. These are compared in Fig 6a. Basically, friction is pressure dependent, and the following formulae are given (for virgin, recessed, dimpled and lubricated PTFE against polished stainless steel):-

a. μ **= 0.8 / (10+**σ), EN1337-2, for "warm" climates, temperatures greater than -5degC
b. AASHTO gives values up to 20% less than these for low pressures < = 20 MPa.

Incidentally, for cold climates (sub –5degC) , e.g. northern Europe, EN1337-2 suggests $\mu = 1.2 / (10+\sigma)$. Southern Europe and Australia can use the **lesser** friction value (a.).

Currently, only at permanent loads need the effect of friction be checked on the bridge. Hence friction at LOW pressures is of most interest in this comparison. One difficulty is that PTFE pressure is unknown to the bridge designer at the time of sizing his piers, or summing friction at anchor piers, etc - hence a reasonable simplification of 3% is suggested in AS1500.4 (recessed PTFE). This is adequate for all but the highest nominal LL/DL ratios on the coldest of Australian days. Strictly (Fig 6a), LL/DL ratios greater than 1.0 (or 1.5, or even 3.3 depending on temperature) can exceed this convenient rule of thumb, but there is further protection in a load factor of 1.3 for friction. As bearing designers however, may we make the case that friction tests carried out "solvent-DRY" prior to lubrication (as some states still require) should be permitted a friction factor of around $1.6/(10+\sigma)$, (>> 3.0%).

The ease of using a standard value of 3% is taken advantage of in the new rules in AS5100.4 for "summing" adverse and relieving friction effects at a number of piers (Fig 6b and 6c), where otherwise friction factors at each pier are presumably pressure dependent.

4.00 LAMINATED ELASTOMERICS

4.01 LAMINATED ELASTOMERICS, LIMIT STATE APPROACH

LE bearings continue to be designed for SLS effects only, (consistent with ABDC, EN1337, etc). In their design (whether by bridge engineer or bearing supplier), the same parameters feature i.e. Nmax, Nmin, δlon, δtra, Hlon, Htra, αlon and αtra. Again the MORE load cases, the BETTER. Sometimes the maximum ratio of (αlon / N) is given, but without notes on how to handle αtra. (Presumably in these cases αtra can be ignored -eg mortar taper, skew effects)

The only significant changes to the design rules between ABDC and AS5100.4 are :-

- the rotation limit has been reduced from (4.dc/a) to (3.dc/a), to conform to BS5400
- permissible shear deflection has been reduced from 50-70% (var) to 50% AS1523 values (with the same max 20% reduction in projected plan area)
- anchorage requirements have been marginally tightened (Fig 4d.)

Figs 4a show typical "planes" (ref 9) of a typical LE "permissible interaction zone" (similar to Fig 3b for pots), which defines the MAXIMUM load capacity (max pressure, steel plates, stability, total rubber strain, and LL rubber strain). Other checks define the MINIMUM load capacity (min load for rotation, and min load for anchorage). There is also a "MAX shear plane", which is arguably the most interesting (eg Fig 5d). Incidentally, "planes" may be warped, and ALL will never feature together. "Anchorage limits" are easily avoided with dowels or keepers (Fig 4d), with some loss of movement. At any given (uniaxial) rotation and shear deflection, there is a permissible range of compressive loads, as indicated in Fig 4a.

Figs 4b & 5d show the typical Rated loads given in the Standard Tables, Roo, Rro, Ros, and Rrs (where Rro = rated SLS load at max rotation, zero shear; and Ros = zero rotation, max shear, etc, for that axis). It must be remembered that e.g. Rrs is BOTH the maximum AND minimum load at that rotation and shear – and indeed different values of Rro and Rrs apply for the other axis, or for combined axes. The rotations at Rro or Rrs are rarely experienced by a bearing (the tables are intended as a guide only). Incidentally, compression overload testing is carried out at 150% of Roo, and this should be specified for non-standard (client's) designs.

Fig 4c and 4d show the typical case of maximum shear (or near maximum shear), with both Nmin and Nmax, and anchorage effects. In this case, keepers are required at Nmin (Fig 5a).

4.02 TESTING OF COMPLETED LAMINATED ELASTOMERIC BEARINGS

The tests on LE bearings previously specified in AS1523 have now been adapted into AS5100.4. The main difference is that shear stiffness, Ks, is now universally the "mean" or chord stiffness between 5% and 25% shear strain, (or "$Ks_{5\text{-}25}$", introduced in ABDC). This is about 10% less than "Kso" in AS1523, just as G or "$G_{5\text{-}25}$" in AS5100.4 = 0.69MPa, and "Go" in AS1523 = 0.77MPa. This test for shear stiffness continues to be the main acceptance criteria for LE's, (tolerance on Ks is +/- 20%). Compression stiffness is also measured, but more to check consistency of manufacture - and to choose "similar" bearings for shear testing.

4.03 TABLES OF STANDARD LE BEARING PROPERTIES

Standard LE bearing properties of the familiar AS1523 sizes are updated and given in Appendix A to the standard. These tables are intended to assist in the selection of a suitable trial bearing, which should be checked against the detailed design rules of this standard. The tables only apply to uniaxial shear and rotation (minor axis) – different values apply to the major axis, or combined axes, and "anchorage" and "rubber strain at live load" are unchecked.

The SAA Part numbers are as per AS1523, eg **SAA 20:21:11C**, Size 20 = 880 diam, 11 layers at 21mm. This is the largest standard bearing, and is shown under load (Fig 5b), together with its "interaction zone" (Fig 5d). As an aside, it is evident that none of Roo, etc are of much help to a designer to compare with his SLS loads. More practical and user-friendly is a nomenclature such as **LE 6460 / 2350 / 0.01r #124**, where e.g. the R0.01r rated loads are given. Hence, at 0.01rads and +/-124mm δx shear, the load can range from 2350 to 6460kN. This is more relevant that, say, Rrs (at 'some max rotn', load must be 'exactly' Rrs= 4395kN) But for 'optimal' use of LE bearings in all modes, these design graphs are recommended.

5.00 ELASTOMER TESTING FOR POTS OR LAMINATED ELASTOMERICS

AS1500.4 Appendix B, table B3(A), gives sets of properties for two alternative rubber hardnesses. Either is acceptable, provided the correct design properties are achieved and used, tensile strength, elongation, and shear modulus G in particular (Fig 9). It is most common (though not mandatory) that plain pads and bearing strip be of type 60H (or 60 IRHD) rubber, while pots and laminated elastomeric bearings be of type 53H (or 53 IRHD). Note that shear modulus G is strictly a laboratory term, determined by the Quad-Shear method of testing without any compression whatsoever (Fig 10). The term is loosely applied to the estimate obtained from shearing completed bearings, usually under a compression load of 2MPA (only). The tolerance on G in the quad shear is +/-15%, and in LE's it is +/-20%.

There are many tests covered in App B. We emphasise two only, namely the "Curemeter" test, and the "Hardness" test. These two tests are to be carried out on every independently mixed batch of elastomer, no matter how small. The compound to which they belong must have extensive test data on file, including tests proving compliance for all properties for several hardnesses around the mean. The hardness and curemeter results for each batch must lie within proven ranges for that compound or be retested for virtually the full range of tests.

Curemeter. The Curemeter test, Fig 7, is the major QA acceptance criterion for each batch. This test is a well established and commonly practiced quality control tool to prevent batches with incorrect parameters passing through to production. It checks the rate of vulcanisation reaction, plotting shear resistance (whether oscillating disc or moving die) against duration, and manufacturers use it to pick up compound variability and check acceptable limits at various stages (known as "gates"). Typically four or five gates are chosen to double-check cure rates and general processibility. An aberrant batch would be quarantined.

Hardness. Strictly this is measured in IRHD (International Rubber Hardness Degrees), Fig 8. However the hand-held Durometer Shore A hardness scale is a popular "quick check" because it can be carried out without using elaborate laboratory apparatus. Any claims as to the interchangeability of IRHD and Durometer A readings, with a small correction as necessary, should be demonstrated by the manufacturer using both methods on the same sample.

6.00 CONCLUSION

AS 5100.4 represents a significant change to the previous code ABDC, generally more conservative, with a major influence from EN1337. The requirement for larger bearings will inevitably clash with space constraints at piers, and will demand more attention to bearing design. For pot bearings, examples are given of how to specify the performance requirements at ULS and in the correct detail to permit the bearing manufacturer to complete an economical and adequate design. We would argue that some gaps still exist in AS5100.4 (eg distribution angle and mortar pressure), but these should be addressed in the Bearing Questionnaire of any competent bearing designer. Suggestions for a supplier's "Design Submission" are given.

LE bearings are frequently designed by the bridge (or building) designer, although they can also be specified by the appropriate SLS design parameters for the supplier to design. Again the necessary parameters are discussed, as well as the use of the "Standard Design Tables". Details of testing of elastomer is included, finally completing the transition from AS1523.

7.00 REFERENCES & AUTHORS

1 Australian Standard AS5100.4, "*Bridge Design, Part 4, Bearings & Deck Joints*"
2 Australian Code:- '92/96 "*Austroads Bridge Design Code, Part 4, Bearings and Deck Joints*"; also known as SAA HB77.4-1996, (abbreviated to ABDC)
3 Australian Standard AS1523-1981, "*Elastomeric Bearings for Use in Structures*"
4 British Standard BS5400 Sections 9.1 and 9.2 :1983 "*Code of practice for design of bridge bearings*" and "*Specification for materials, manufacture of bearings*"
5 European Standards EN1337-1 and EN1337-2 "*Structural Bearings - General Design Rules*" and "*Sliding Elements*" resp, (abbreviated to EN1337)
6 Draft European Standard prEN1337.5 "*Structural Bearings - Pot Bearings*"
7 American Standard "*AASHTO LRFD Code Section 14 Joints and Bearings (SI)*"
8 EGGERT H., and KAUSCHKE W., (2002) "*Structural Bearings*", ERNST & SOHN
9 DAVIDSON G., "*Quality Assurance and Specifications around ABDC for Bridge Bearings*", Austroads Conference, 1991, pages 631 – 644
10 KAUSCHKE W. and BAIGENT M. *"Improvements in the Long Term Durability of Bearings in Bridges, Especially of PTFE Slide Bearings"*, 2nd World Congress on Bearings and Deckjoints, San Antonio, 1986, pages 580-581.

11 Graham Davidson has experience in bridge design, but since 1978 has specialised in the supply of bearings, vibration isolation systems, and deckjoints throughout Australasia & Asia (Repco Glacier, Hercules, and Ludowici). Designs include Anzac Bridge, Sydney; Singapore/Malaysia Crossing; and Bayu Undan, Timor. Code Committee Member, AS5100.4, and author of five similar papers.
12 Chito Sarmiento also has a background in structural engineering, and has specialised in bearings since 1999, (Hercules Engineering and now Ludowici).
13 Cec Williams has a total of 40 years experience in the industry, including the formative years with Advanx as pioneer suppliers of LE bearings in the 1960's. Chief Chemist and Manager of Ludowici's NATA Laboratory in their Sydney factory. Code Committee member, AS1523, and others.
14 Neil Robinson has specialised in LE bearings (and the technology and testing behind them) since joining PJ O'Connor / Ludowici in 1976. During the 1980's this team took the design and manufacture of LE bearings to new internationally recognised levels, with the manufacture of the Westgate Freeway LE bearings.

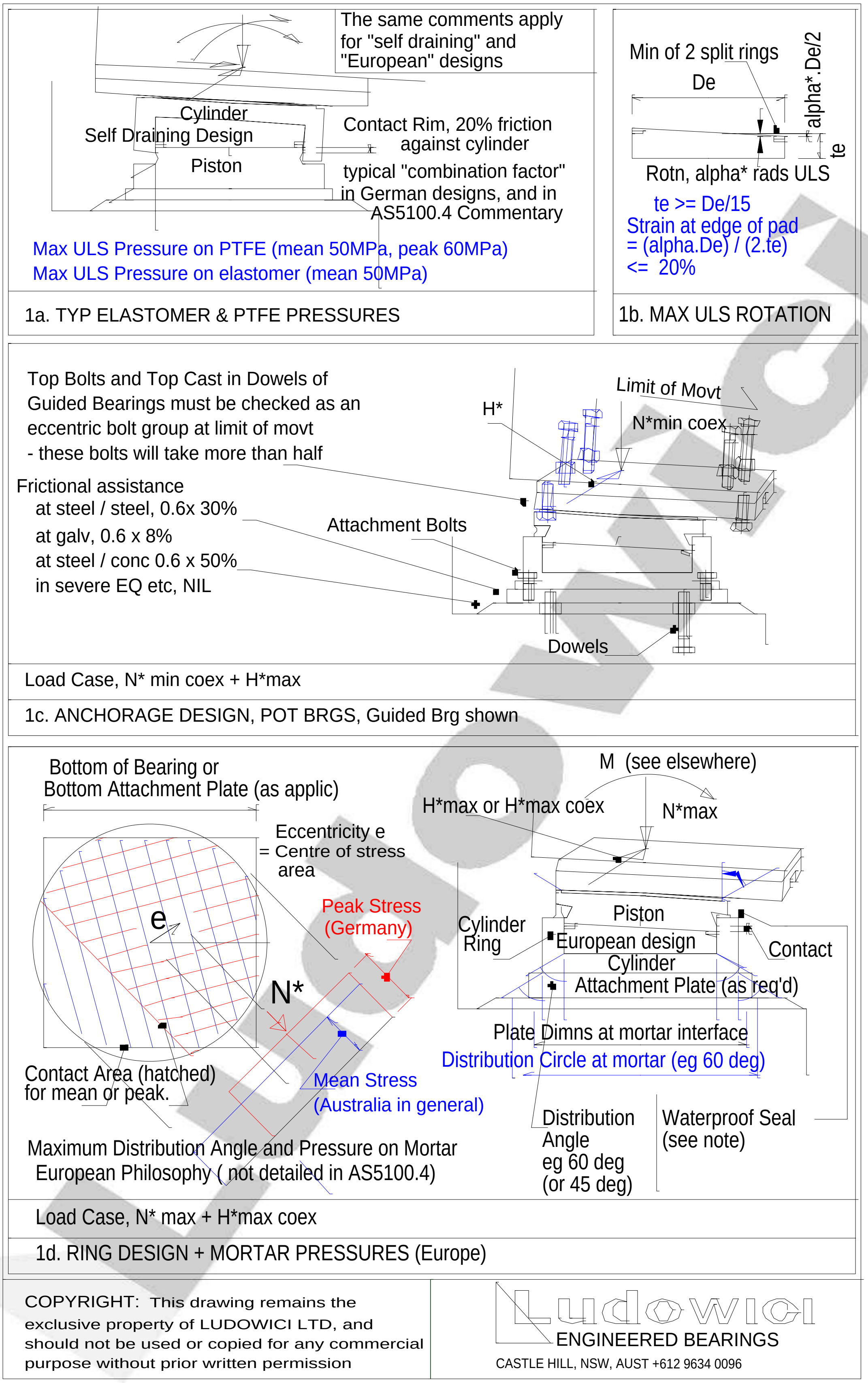


Fig 1. Design Checks for Pot Bearings; 1a.Elastomer and PTFE Pressures; 1b. Max Rotation; 1c. Anchorage Design; 1d. Ring Design and Mortar Pressures (Note that the waterproof seal in 1d. should arguably remain so for the full rotation range).

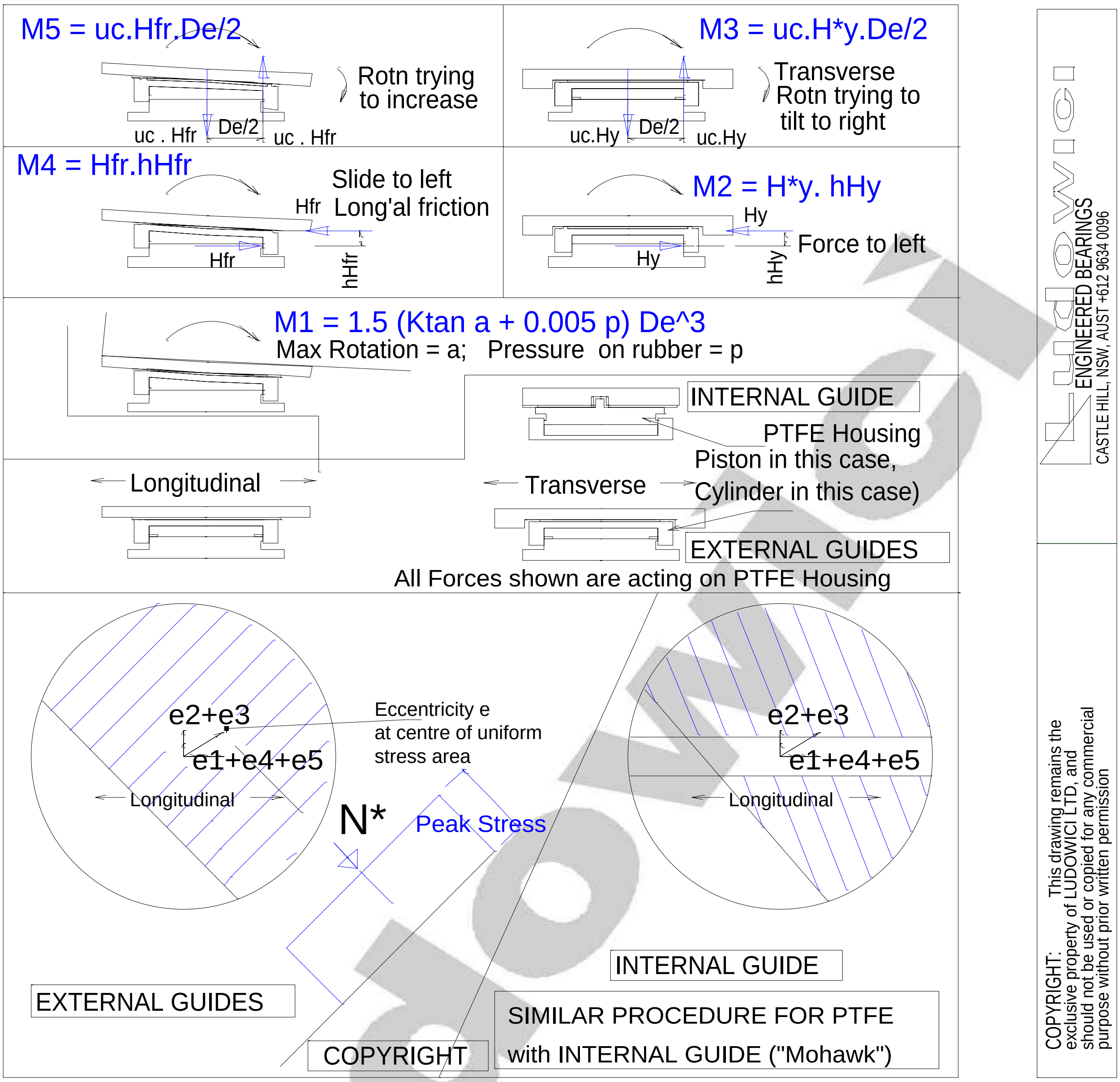
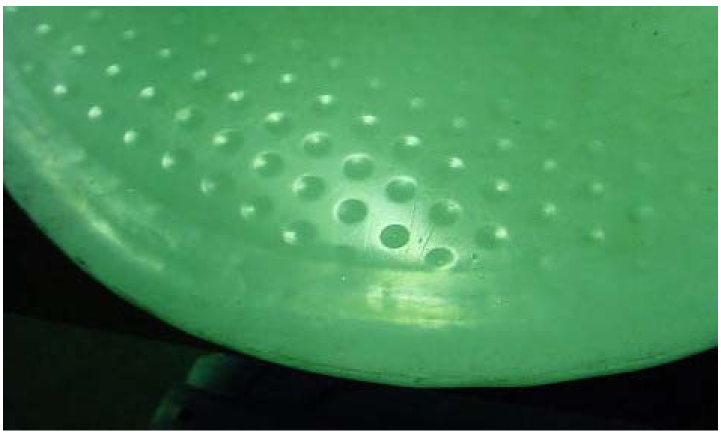


Fig 2a. Typical Potential Moments on the PTFE, and Use of the Uniform Stress Block for a Longitudinally Guided Bearing (either External Guide or "Mohawk" Internal Guide

Fig 2b. There are two principal ways that PTFE can experience the distress shown at right, namely

- *excessive pressure (caused by overrotation and/or overload), and*
- *dislodgement if unbonded (as is the cause in this case – bonding is not currently insisted upon in AS5100.4)*



Identifying Mark of bearings		#B12, #B14, and #B16	
Type and Description of bearing		Guided Longitudinal	
Number of Bearings		3	
Load Combinations **(In each case, a range of N* values for a set of H*, δ* and α* values.)**		(N*max or N*min) + H*coex	(N*max coex or N*min coex)+ H*max
Compressive Load Range	N* max (kN)	8000	6000
For these parameters	N* min (kN)	2000	3000
Horizontal Load	H*tra (kN)	600	1600, (ship)
(can coexist)	H*lon (kN)	Friction only	Friction only
Displacements (can coexist), + =expansion	δtra (mm)	+/- 2 limit	+/- 2 limit
	δlongitudinal (mm)	+200, -300	+200, -300
ULS Rotations, (**)	αlon, tilt in long'al dirn	0.010 rads	0.010 rads
(can coexist)	αtra, tilt in transverse dirn	0.005 rads	0.005 rads
Is Frictional Assistance Permitted for Anchorage ?		Yes	Yes
Maximum pressure (60deg distribution) on mortar		30MPa ULS	30MPa ULS

Fig 3a. Typical Pot Bearing Performance Schedule, to accompany sketches of layout, and of bearings with contact surfaces, attachment plates, etc as required. For uplift or fatigue refer notes. It is desireable that design cases and tests be confirmed in a "Design Submission HOLD POINT".

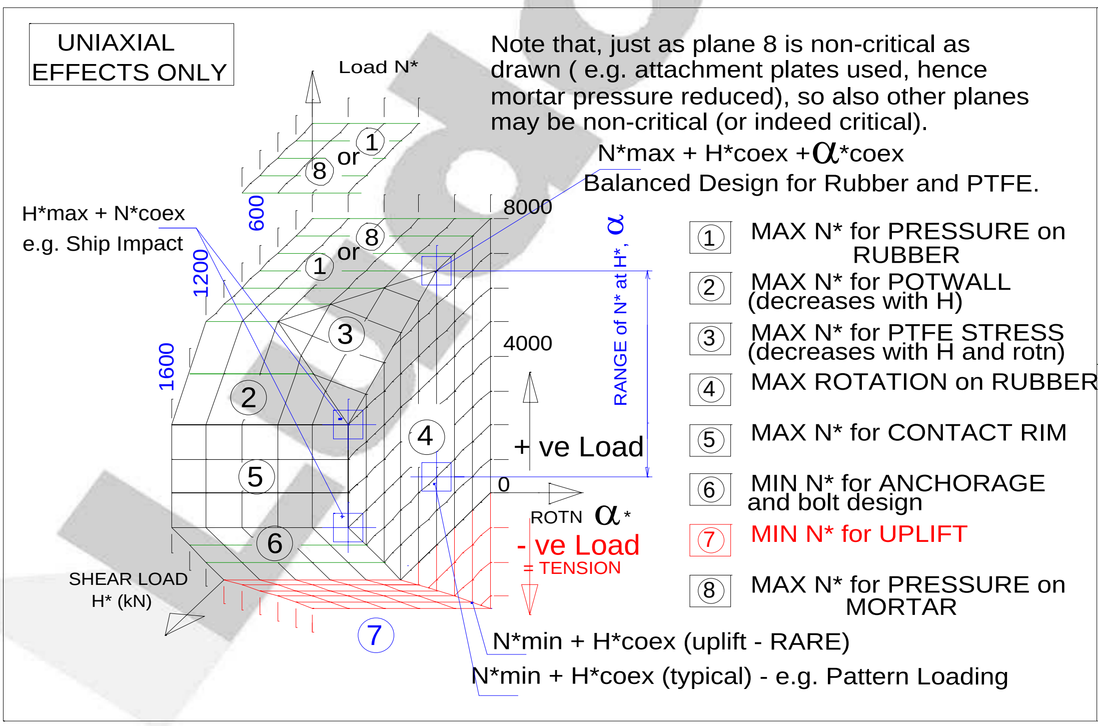


Fig 3b. The Concept of Pot Bearing Permissible Interaction Zones- Indicative Only. Ranges of N* from the above Table are indicated. To assume that either of N*max (eg MS1600 pattern load 1) and N*min (eg MS1600 pattern load 2) can coexist with H*max (eg ship impact) would expand the zone to the enveloping "box". This is obviously an unrealistic loadcase. Note that uplift is permitted in AS5100.4, where it is not in EN1337 for instance.

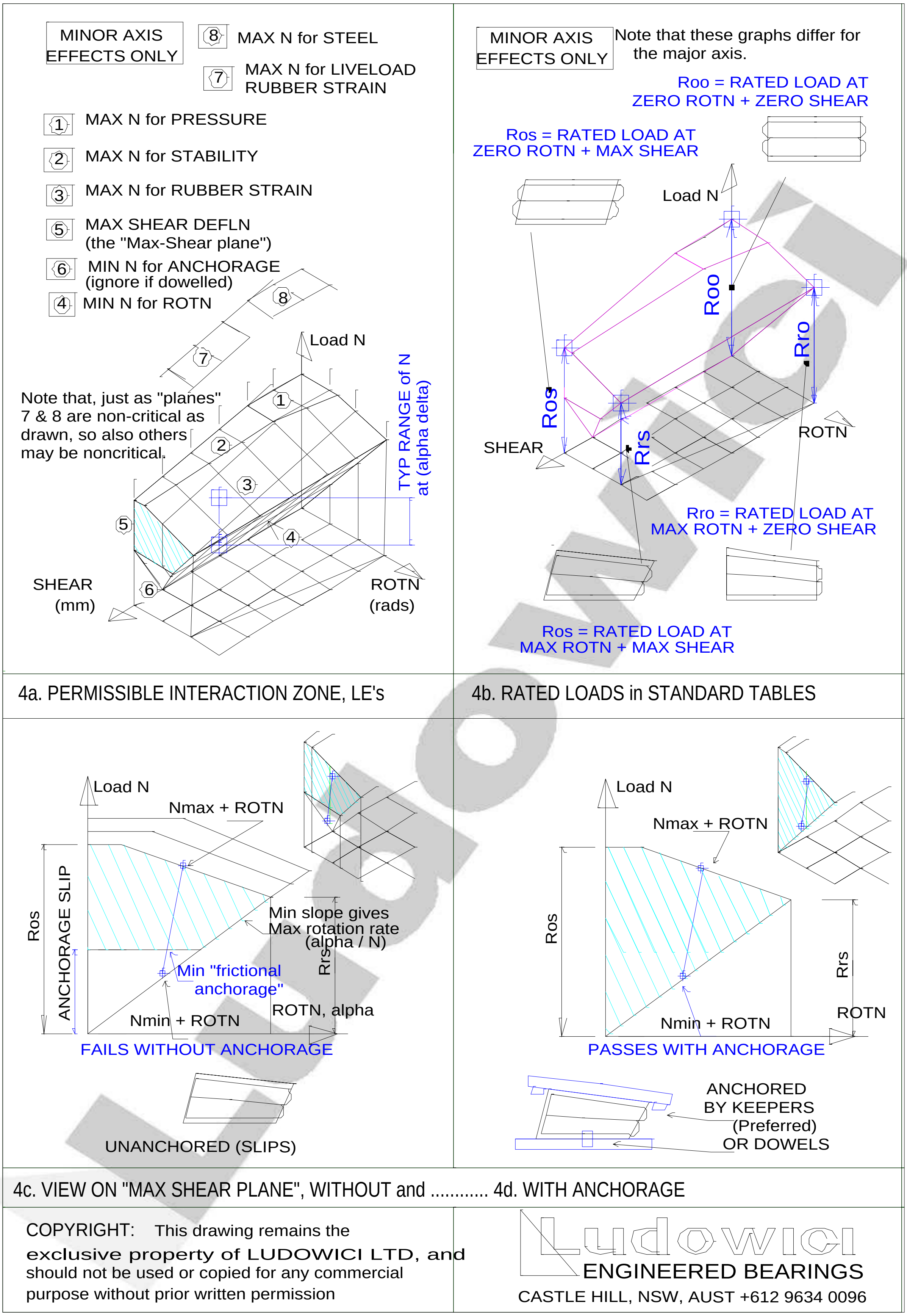


Fig 4. Laminated Elastomeric LE Design Checks 4a. Permissible Interaction Zone 4b. Rated Loads in Standard Tables 4c. Max Shear Plane 4d. Anchorage Effects Note that none of the classic "Rated Loads" Roo etc apply at typ "DL" or "Full Load".

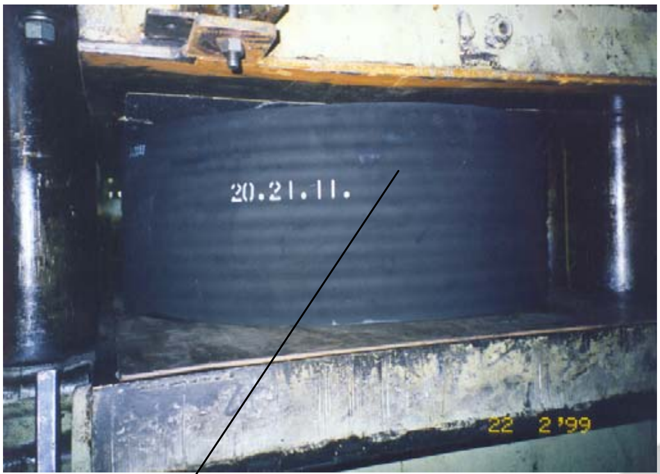


Fig 5a.. Top Left – Melbourne's Westgate Freeway brgs (up to 750x1050x330) are massive 18 MPa designs. "Ahead of their time", they were built in the mid 80's, and include keepers to prevent slip or "walking".

Fig 5b. Above – The largest rectangular and circular bearings of the AS5100.4 standard sizes, 600 sq x 293, (10:18:12R) and 880 diam x 309, (20:21:11C) resp.

Fig 5c. Left - The SAA 20:21:11C bearing under compression load.

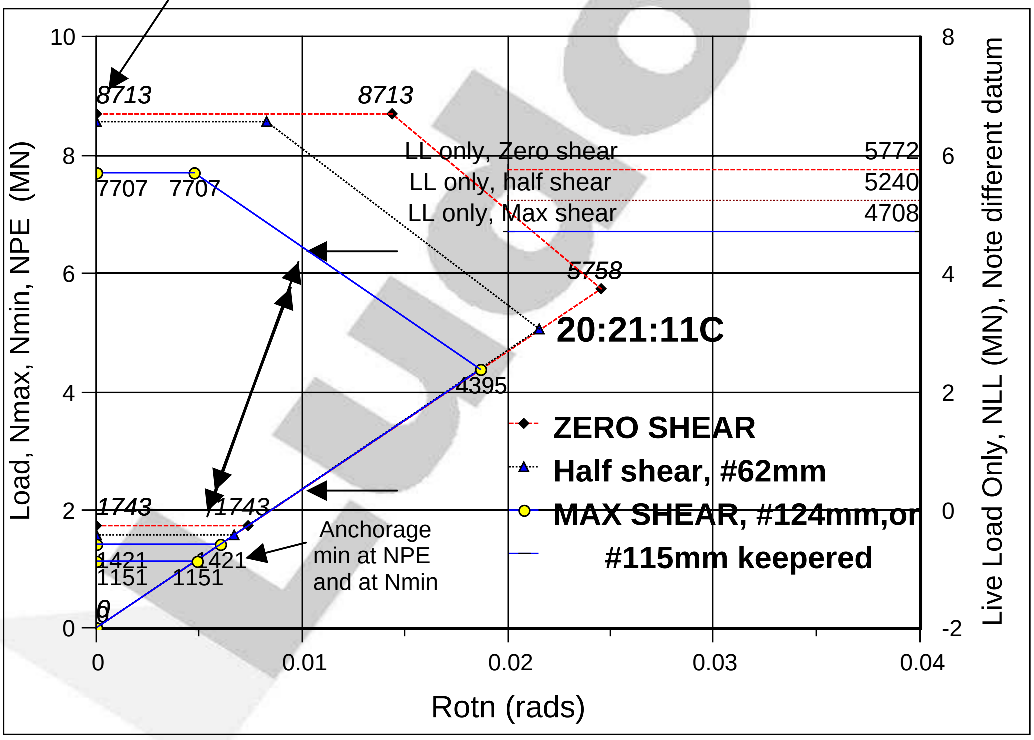
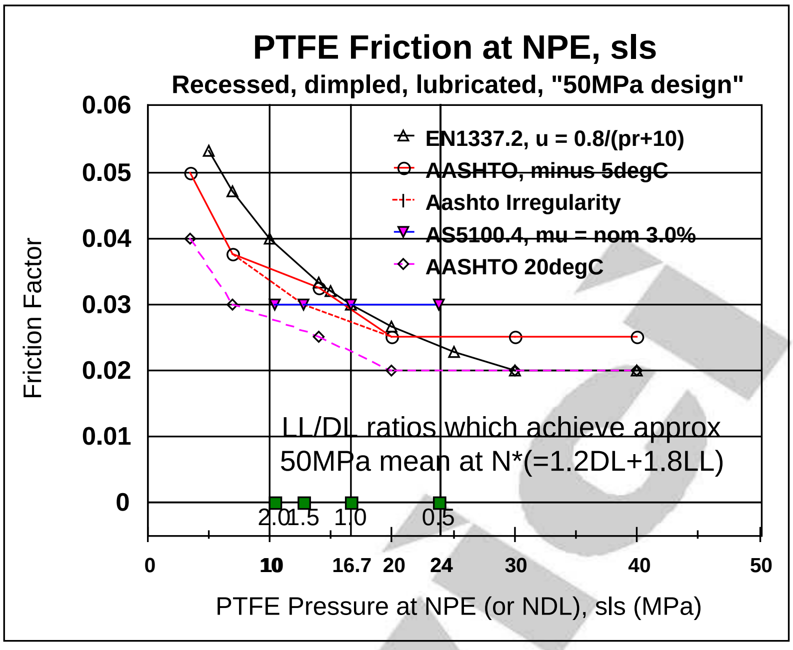


Fig 5d. The Interaction Zone for the circular bearing design above, 20:21:11C, showing the three graphs (zero, half, and maximum shear). Note Roo=8713, Ros=7707, Rro = 5758, and Rrs=4395kN; Max shear is incidentally#124mm, or #115mm "keepered". Low limits at 1421kN etc are easily avoided with keepers, and Live Load limits, NLL, are shown to a different datum.
Its maximum sls load range at, say, R0.01r #124s = 0.01 rads, & 124mm shear, is 6460 to 2350kN (refer ← signs), hence we propose LE 6460 / 2350 / 0.01r #124 as a more user-friendly nomenclature. Typical range, Nmin to Nmax, (with double arrows) still benefits from a closer check of the graph.

Fig 6a. PTFE Friction vs Pressure. Note that EN1337 and AASHTO differ, and that there is an "irregularity" in the AASHTO graph at around 14MPa (2000psi, -5degC).

AS5100.4 suggests a 'uniform' 3% at 'typ' DL pressures, and the commentary gives the EN1337-2 formula for high LL/DL ratios.



Also shown (at relevant NDL pressures) are the ratios of nom LL/DL which achieve 50MPa at N=1.2DL+1.8LL. This is the design mean pressure on the PTFE, and its "probable" size. E.g. If LL/DL = 1, then (N*/NPE) will be app (1.2+1.8x1)=3, and the pressure at NPE will be [50 / (1.2+1.8(LL/DL))] = 16.7MPa. The 3.0% value is marginally unconservative for LL/DL ratios greater than 1.0 (cf EN1337-2), or "about 1.5" (cf AASHTO), or even "about 3.3" (cf AASHTO, 20degC, 7MPa = 3%). Obviously higher temperatures mean that higher LL/DL ratios still remain under 3%.*

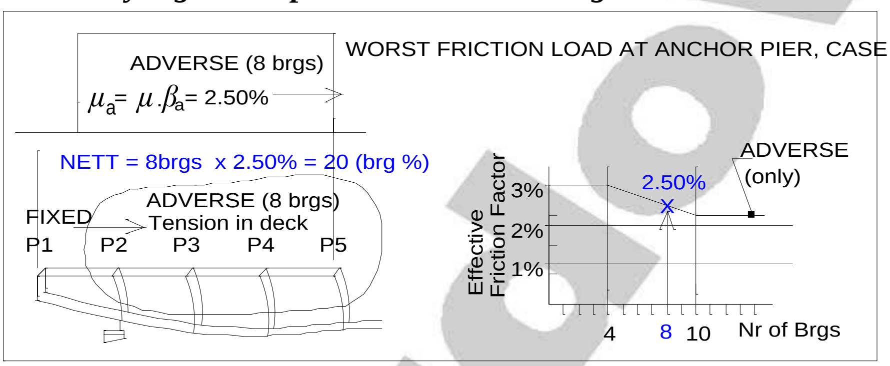


Fig 6b. Accumulated Friction Force at Anchor Pier, with 8 slide brgs, all adverse. The friction is downgraded to 2.5% under these circumstances, for a total of 20 "bearing %", (hence Hfr sum = 20%NPE).

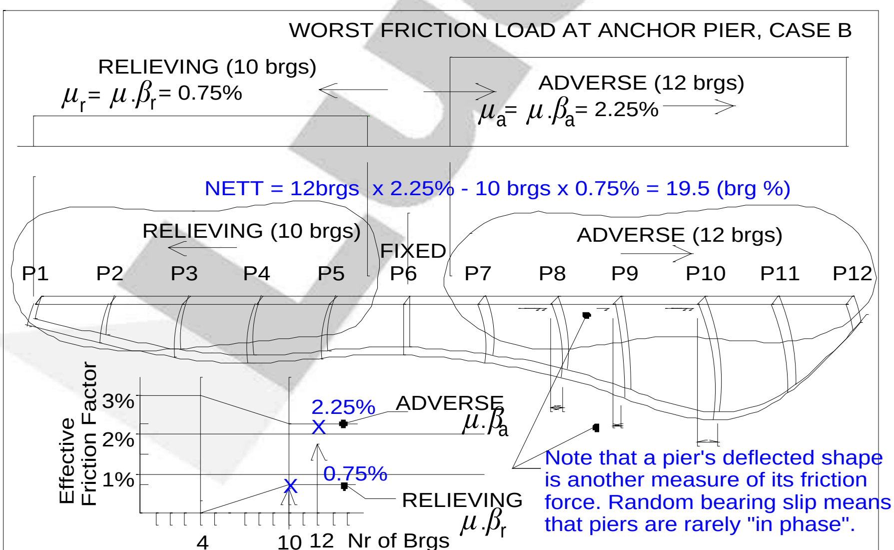


Fig 6c. Accumulated Friction at anchor pier, with 22 slide brgs, 12 adverse, 10 relieving. Note the values of +2.25% and –0.75% resp, for a total nett force of 19.50 "bearing %". This is almost the same anchor force as for Fig 6b above.

These are drawn for cold deck, when highest friction occurs - codes ignore this subtlety.

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Fig 7a. – Left – Curemeter to check the correct batching of components. Note samples collected before and after test.

Fig 7b. – Lower left - Raw components for a natural rubber mix (left), or synthetic mix (right).

Fig 7c. – Lower right - Various raw elastomers (natural rubber in the foreground).

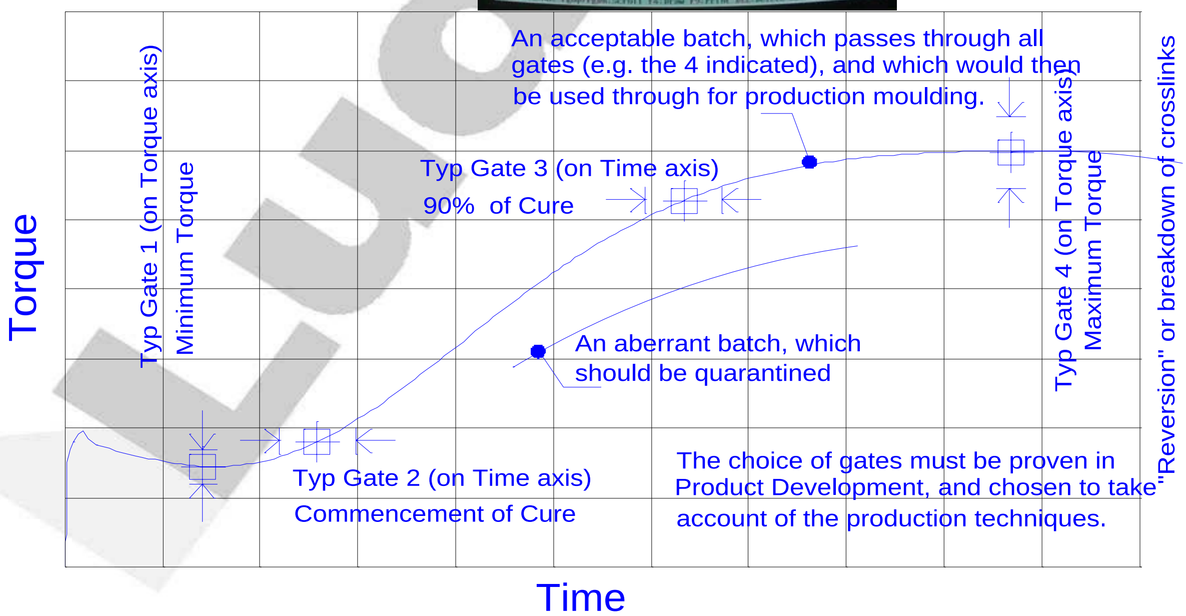


Fig 7d. Typical Curemeter Graph for an ODR Oscillating Disc Rheometer. Note that an alternative Curemeter is the MDR or Moving Disc Rheometer, which likewise measures rate of the vulcanisation reaction. The data and its treatment are similar in principle.

Fig 8a. IRHD Hardness Tester (International Rubber Hardness Degrees) in the background. This is a laboratory machine operated at controlled temperature (23 +/- 2degC), and carefully timed at 30 seconds (method N as specified).

The hand - held Durometer A tester relies on the skill of the operator to apply 1 kg of compression, and is much more prone to scatter of results.

Standard hardness blocks are also available for checking equipment.

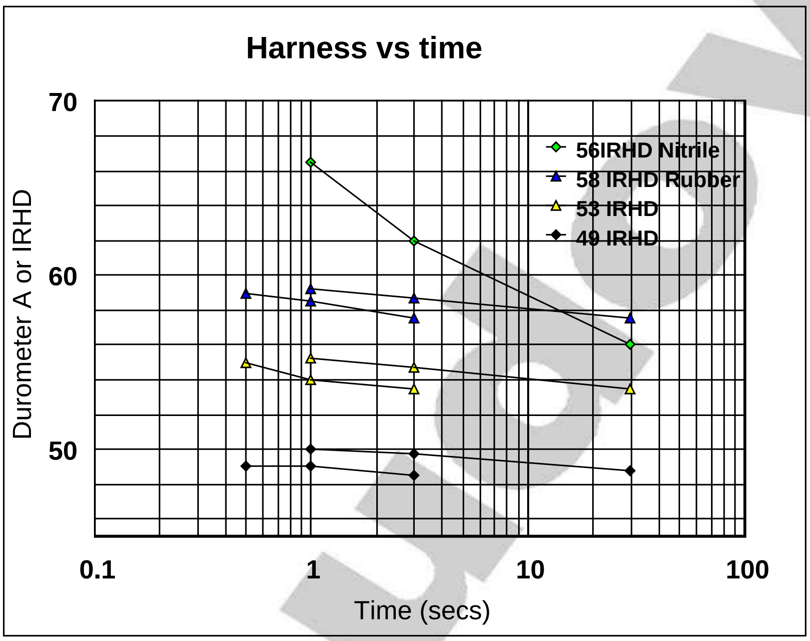


Fig 8b. The graph of hardness vs time shows some creep (particularly for of nitrile as shown). Rubber is shown varying 49 to 58 around a 'mean' of 53 IRHD (refer the 30 sec value).

This is an example of a "proven range" where extremes must have a full set of test data on file, and also must not exceed +/-5 IRHD of nominal.

The 3-second Duro A value is frequently closest to the true (30 sec) value of IRHD, although, the 1 second value is mostly used.

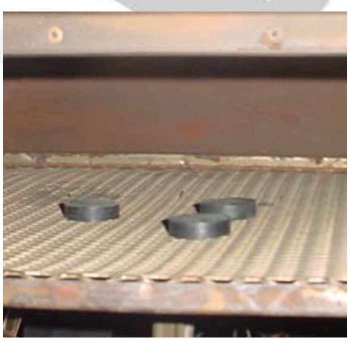
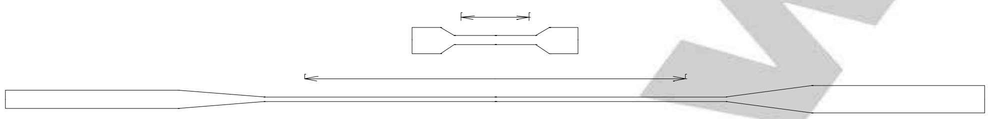


Fig 8c. Hardness "buttons" (in oven ready for accelerated aging test) should not increase in hardness (or decrease – but usually increase) by more than 4 IRHD after 7 days at 70degC (a test required quarterly in AS5100.4). Nor incidentally should they increase by more than 5 IRHD after 24 hours at –10degC (a yearly test).

Fig 9. Tensile testing for "Tensile Strength, uts, and elongation at break, eb". The photos are to similar scale. Note that the elongation at break, eb, must be at least 575% for 53 H rubber, and that this value was critical in the LE design rules to AS1523.1981.



Tensile Strength, and Elongation at Break eb

Fig 10. Quad- shear testing to determine the "true" value of the shear modulus, G. Note that the four small rubber samples are bonded to the grip plates for this test, and there is no compression applied. This value is now the basis for designing LE bearings to AS5100.4, having displaced "eb" in these equations.

Fig 11a. Top- Samples for testing are moulded and cut from thin sheets. This shows some of the knives and samples for the tension test, the quadshear test, the tear test, compression set and hardness buttons. Most are quarterly tests, although hardness checks are required on EVERY batch, and quad shear is yearly (with low temperature and ozone tests).

Of course if a batch is "out of specification", then it will require many of these tests repeated before it is accepted.

Fig 11b. Left Top – Tension and compression set samples undergoing accelerated aging at 70ºC.

Fig 11c. Above – Refrigerator for Low Temperature tests (many are beyond the requirements of AS5100.4, such as the low temperature compression set test). Independent sensors are required at each compression set jig. Simple low temperature stiffening is required however, and this is a yearly test.

Fig 11d. Right – Ozone Test Cabinet – with controlled ozone concentration, temperature and flow.

Fig 12a. Anzac Bridge, Sydney, and the largest pot bearing in Australia (with a capacity of 46000kN SLS), designed and tested to 50000kN by G. Davidson whilst at Hercules Engineering, 1992.

Under AS5100.4 rules, this would be permitted only 57500 kN ULS (based on rubber pressure of 50MPa ULS), say 57500 /1.5 = 38300 kN SLS, a 16.7% reduction. Note the attachment plates to achieve an acceptable contact pressure on the mortar (and to facilitate removal).

This bearing is effectively a load cell, fitted with a load monitoring transducer, and is designed for fatigue shear load, using Gr8.8 (TF) friction type bolts (usually Gr8.8/S). This concept is similar to the frictional assistance due to gravity discussed in 2.05.

Fig 12b. Bayu Undan Gasfield, Timor Sea. This bearing is of stainless steel, and designed to operate in an aggressive off-shore marine environment at high temperature. Note the polish of the slide counterface, and the (extremely rare) ability to regrease the slide face.

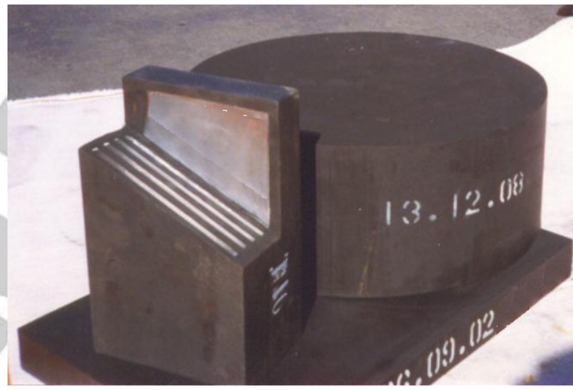


Fig 12c. Small LE bearings, including a "tall" 13.12.08C bearing with its compression capacity based on stability; and a "squat" 06:09:02R (non-standard), with its capacity based on a max pressure of 15MPa on the bonded area. The sectioned bearing is custom-designed, and shows the standard 5mm plates required to satisfy AS5100.4.

Fig 12d. Citigroup Building, CBD, Sydney, which is part mounted on LE vibration isolation bearings. Note that parallelism of plates is particularly important for the stability of tall bearings. Uniform bulges give a non-destructive indication, and stability tests can also be performed (common for vibration isolation bearings under buildings), but these tests are outside the requirements of AS5100.4.