Rotations to Building Bearings

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The structural engineering world is changing. Spans are getting larger, whilst structural material is becoming lighter. It is thus no wonder that the effect of cracking in building materials due to deflection effects, together with the nuisance from vibrations onto structural floors is increasing. The education of structural engineers has remained too static, with a shift towards a more dynamic approach now more appropriate in our age. Simple statics, although possibly not too simple, without consideration of serviceability is thus not sufficient in designing member sizes. In Issue 59, I wrote on deflection and vibration effects - various ratios were then delved into, outlining deflection/vibration hand methods that may easily be adopted in design offices to engage on a particular ratio as considered to cause least disturbance for the use/s anticipated. This note demonstrates that it is an even easier step to go from a deflection span ratio onto a rotation calculation, as a simple relation connects these criteria.

Reference to Rotations in Standards

If deflection and vibratory effects are engaged at some stage of the design process, less and less is catered for in the rotations arising at the bearings of structural elements. Details may be found in Ciria Technical Note 107, "Design for Movement in Buildings", 1981, which refers to rotations and quotes "quite small rotations or changes of section at the supports (such as occur in reinforced concrete because of cracking) cause relatively large increases in deflection." It is then suggested that "sliding and movement joints may thus be necessary to avoid cracking and rotation for brickwork construction." A movement detail for a precast element then notes that a shortening in bearing length, further compounded by translation due to rotation could lead to serious shortcomings. However, further to a suggestion not to rely on full fixity in calculating deflections no further concrete guidance is given on allowable rotations, just prudence advocated.

BS8110 notes that when large rotations occur, without defining what is large, suitable bearings should be used. Reference is then made that these rotations may throw the line of action onto the outer face, necessitating larger bearing stresses. EC2 refers to where a beam or slab is continuous over a support which may be considered to provide no restraint to rotation (e.g. over walls), the design support moment, calculated on the basis of a span equal to the centre-to-centre distance between supports, may be reduced by an amount calculated as:

(i) $\Delta M_{Ed} = F_{Ed, sup}\, t/8$, where $F_{Ed, sup}$ is the design support reaction and t is the breath of the support.

The allowable plastic rotation is then given at 0.015rad and 0.035rad varying on the grade of concrete and steel adopted. Again, EC0 Basis of Structural Design quotes rotations varying within the same limits. EN codes on bearings refer to rotations, however specific and clear criteria may be gleaned in a PCI report, Technical Report No 4, "Criteria on the Design of Bearing Pads", 1985, where a simplified method catering for rotation in bearing pad design is suggested. This report noted that most codes related to large bridge bearings with small pads required in buildings regulated to a secondary position. The tasks of this report were to develop adequate design criteria for precast concrete buildings.

Table 1: Prestressed transfer planks on a 6.5m deflection/rotation characteristic

Slab depth mm	Safe Loading kN/m²	Span:Total Deflection ratio A	Span:Depth ratio	Rotation at support in radians = 3.2/A
250	15	1: 533	26.00	0.006
330	20	1:1,155	19.70	0.0028
450	55	1:1,293	14.45	0.0025
500	65	1:1,352	13.00	0.0024

Support Rotation Calculations

For a uniformly distributed load w acting on a simply supported girder of effective span l, the end rotation is given by:

(ii) $\theta = (wl^3/EI)/24$, where EI is the flexural rigidity of the structural material

The mid-span deflection divided by the span length, the span deflection ratio, is given by:

(iii) $\Delta/l = (5wl^3/EI)/384$

The ratio between these equations works out as:

(iv) $\theta/(\Delta/l) = 1/24/\,(1/384) = 3.2$

Similar calculations for a single concentrated load at mid-span give a ratio of 3.0. The end rotation consistent with a u.d.l. deflection of l/800, is given at:

$\theta = 3.2 / 800 = 0.004$rad.

The end rotation for any other deflection limit can be obtained directly by scaling down or up as necessary. For continuity over two or three spans, the mid-span deflections and the end rotations (at the central support) are multiplied by factors as obtained from National Cooperative Highway Research Program (NCHRP) report 596, "Rotation Limits for Elastomeric Bearings", 2008.

As in multi-spans the end rotation decreases more than the mid-span deflection, the net effect is to reduce the end rotation if the mid-span deflection is still controlled by the l/800 limit. If the entire load is treated as distributed, the largest possible end rotation is (0.50/0.70)*(0.004) = 0.00286 radians for two spans, and (0.40/0.52)*(0.004) = 0.00308 radians for three spans. These factors have also been referred to in the Note delving on deflection/vibration effects.

Calculations then compile an (amplified) rotation made up of:

Allowance for uncertainty:	0.0050
Thermal camber:	0.0015
Loading:	0.0040
Total:	**0.0105 radians**

In particular, the allowance for uncertainty is a very small angle given as 0.005 radians. This corresponds to a movement from centre of about one tenth of the bubble length in a carpenter's level. Thermal effects can cause camber in the superstructure. It is typically largest when the sun shines on the roof deck, which absorbs radiant heat and expands, with its effect being comparable or even larger than that of the applied loading. Protected intermediate floors will be subjected to a smaller overall rotation given at 0.0105 – 0.0015 = 0.009 radians.

Reference is being made to Table 2 in the previous technical Note (Issue 59). This is reproduced here as Table 1, with the additional final column referring to rotation at simple spanning support in radians. This column is obtained as noted from above equation (iv) by dividing the 3.2 constant with the span/total deflection ratio as obtained from column 3 in Table 1.

The rotations quoted in Table 1 note the largest rotation at 0.006 radians as obtained from the 250mm shallowest depth with however, the lowest load capacity at 15kN/m². The lowest rotation at 0.0024 radians is obtained from the highest section depth 500mm, having the highest load capacity at 65kN/m².

The amplified rotation, as above for these sections is given at:

225mm section depth 0.005 + 0.0150 + 0.006 = 0.0260rad
500mm section depth 0.005 + 0.0150 + 0.0024 = 0.0224rad

These rotations lie within the allowable rotation limit as quoted above, lying between 0.015 and 0.035rad. There surely must be a correlation between the imposed bearing rotation and the bearing stress block shape. Whether the stress block is rectangular, triangular or even parabolic in shape must be dependant on the rotation of the supporting member.

Now it is known that various crack patterns occur to roof top constructions when concrete and concrete blockwork are used in combination. The concrete slab slides over the supporting blockwork with the resulting, generally horizontal crack pattern formation sometimes even extending up to 4 courses below the seating level of the concrete slab. This cracking has always been advocated as arising due to the thermal movements occurring. It however appears, that the bearing rotation imposed has a greater say in the creation of the crack patterns formed. This as being more conspicuous at the upper levels, due to uplift occurring due to the low imposed dead loading existing.

With respect to the uplift created for the 250 unit at -0.26mm in an internal environment, this crack pattern that might arise is not normally visible. The loading from the overlying floors, if great enough, cancels out any uplift that tries to develop.

Conclusions & Recommendation

An easy relationship exists, noted in equation (iv), to convert span to deflection ratios by a constant 3.2 to rotations in radians. However, it is noted that unlike major bridge structures, relatively little importance is given to the rotation bearing seating capacity for buildings. The effect induced by rotations was noted to increase for exposed structures, with increased rotations noted for lighter sections, even though subjected to much lighter loadings.

Crack patterns have been known to exist for roof structures and possibly attributed to thermal and shrinkage cracking. The placing of a plastic sheet material prior to the casting of a concrete slab has been advocated in order to mitigate crack formation. This detail has not always been successful and the above demonstrates that there exists more than just thermal movement, with rotation at the support being the major cause for this cracking.

These two technical notes have advanced the preliminary design as undertaken in structural engineering to obtain preliminary member sizes. Previously preliminary design was solely based on the strength criteria. Now deciding upon the required span deflection ratios at preliminary design stage for the particular building uses in order to mitigate future damages that may arise from subsequent deflection, vibration and rotation effects, the required moment of inertia I, is calculated. This calculated I may cause section sizings to be greater than those obtained solely from the previous limited strength calculations.