

# Supplementary Material

Fleet-scale evidence and a testable coupled mechanism for radial-raceway spalling in an offshore 5 MW three-row roller main bearing

The following tables provide detailed calculation inputs, system-level model outputs and sensitivity cases supporting the main manuscript. They are supplementary engineering data and do not constitute independently calibrated field measurements unless explicitly stated.

Table S1: Full rating & system FEA output table

| Item                             | Key result                                                                                                       | Meaning for mechanism analysis                                                                                                             |
|----------------------------------|------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| Calculation standards            | ISO 281; ISO/TS 16281                                                                                            | Standardized basis for nominal life and static capacity                                                                                    |
| Fatigue equivalent condition     | $F_a = 801.6 \text{ kN}$ ; $F_r = 2266.0 \text{ kN}$ ; $n = 10.1 \text{ r/min}$                                  | Consistent with the radial-load order used in this paper                                                                                   |
| Radial raceway dynamic capacity  | $C_{\text{dyn,rad}} = 7912 \text{ kN}$                                                                           | Nominal dynamic capacity exceeds equivalent radial load                                                                                    |
| Radial raceway static capacity   | $C_{0,\text{rad}} = 10209 \text{ kN}$                                                                            | Static capacity margin is not the primary weak point                                                                                       |
| Minimum static safety factor     | Axial 3.03/3.06; radial 4.45                                                                                     | The rating report judges static raceway strength sufficient                                                                                |
| Combined modified reference life | $L_{h10mr} = 220901 \text{ h}$                                                                                   | Reference-life hours greatly exceed the field calendar exposure scale; calendar months are not treated as operating-hour life consumption. |
| Radial raceway modified life     | $L_{h10r,\text{rad}} = 295536 \text{ h}$                                                                         | Used only to show the nominal rating-life scale; not compared as a survival estimate without unit-level operating histories.               |
| FEA extreme condition            | $F_x = 441.1 \text{ kN}$ ; $F_y = -199.7 \text{ kN}$ ; $F_z = -1858.6 \text{ kN}$ ; $M_y = 24929.2 \text{ kN m}$ | Design-extreme system response supporting deformation plausibility; not a synchronized failure-event state.                                |
| Most loaded bolt safety factor   | $S_{\text{min}} = 1.13$ relative to $R_{p0.2} = 940 \text{ MPa}$                                                 | Connection margin is lower than the common internal target of 1.25                                                                         |
| Maximum global displacement      | 19.42 mm                                                                                                         | System compliance is non-negligible under extreme load                                                                                     |
| Mounting-surface tilt            | 0.17 deg                                                                                                         | May induce roller skew and edge loading                                                                                                    |
| Maximum raceway misalignment     | 0.067 deg on the load-carrying raceway                                                                           | Supports the plausibility of an edge-load sensitivity analysis; it does not calibrate Kedge.                                               |
| Mounting-surface contact         | Generally closed circumferentially, but with local edge gaps                                                     | Local boundary conditions may redistribute load                                                                                            |

Table S2: Complete LM73.5 Bladed design-extreme load data (maxima are not simultaneous unless they share the same load case)

| Component | Extreme | Load case | Value     | Safety factor |
|-----------|---------|-----------|-----------|---------------|
| Fx        | Max     | ue19_2ad  | 1839.2 kN | 1.35          |

| Component | Extreme | Load case | Value       | Safety factor |
|-----------|---------|-----------|-------------|---------------|
| Fy        | Max     | un11_20_  | 1889.5 kN   | 1.35          |
| Fz        | Min     | un11_22_  | -1858.7 kN  | 1.35          |
| Fyz       | Max     | un11_20_  | 1934.6 kN   | 1.35          |
| Mx        | Max     | ua22e_2d  | 12356 kN m  | 1.10          |
| My        | Max     | ua22a_1a  | 22013 kN m  | 1.10          |
| Mz        | Min     | ue13a_1d  | -16336 kN m | 1.35          |
| Myz       | Max     | ua22a_1a  | 22019 kN m  | 1.10          |

Table S3: Radial-load sensitivity from direct discrete evaluation of Eq. (17)

| Radial load Fr | Qmax     | p0        | b        | z $\tau$ |
|----------------|----------|-----------|----------|----------|
| 1.20 MN        | 87.6 kN  | 0.891 GPa | 0.695 mm | 0.542 mm |
| 1.50 MN        | 109.5 kN | 0.997 GPa | 0.777 mm | 0.606 mm |
| 1.9346 MN      | 141.2 kN | 1.132 GPa | 0.882 mm | 0.688 mm |
| 2.00 MN        | 146.0 kN | 1.151 GPa | 0.897 mm | 0.700 mm |
| 2.266 MN       | 165.4 kN | 1.225 GPa | 0.955 mm | 0.745 mm |

Table S4: Prescribed edge-load pressure-amplification sensitivity cases (not calibrated field values)

| Prescribed Kedge | Conditional local pressure pedge | Conditional local shear stress $\tau_{edge}$ |
|------------------|----------------------------------|----------------------------------------------|
| 1.00             | 0.997 GPa                        | 0.299 GPa                                    |
| 1.20             | 1.196 GPa                        | 0.359 GPa                                    |
| 1.35             | 1.346 GPa                        | 0.404 GPa                                    |
| 1.50             | 1.495 GPa                        | 0.449 GPa                                    |

Note: Kedge = 1.20–1.50 denotes a prescribed 20–50% peak-pressure amplification relative to the nominal Hertzian baseline. It is a sensitivity parameter, not a value back-calculated from the 0.067° system-level raceway misalignment.

Table S5: Descriptive case-depth-to-shear-depth ratio ( $\chi$ SHD) calculation data

| Location              | Effective case depth SHD | SHD / $z_{\tau}$ | Interpretation                                                                                    |
|-----------------------|--------------------------|------------------|---------------------------------------------------------------------------------------------------|
| OR_A_1 radial raceway | 1.49 mm                  | 2.46             | Low remaining margin in a worn loaded-zone sample; original manufacturing state not reconstructed |
| OR_A_3 radial raceway | No effective case        | Not applicable   | No measurable remaining case after severe service damage; not an as-manufactured datum            |
| OR_B radial raceway   | 4.87-5.03 mm             | 8.04-8.30        | Depth margin exceeds shear-depth screen but is lower than selected axial sections                 |
| OR_B axial raceway    | 6.07-6.29 mm             | 10.02-10.38      | Selected unworn axial reference; broader circumferential baseline still required                  |

Table S6: Local contact pressure map input cases

| Case                                        | Fr        | K <sub>edge</sub> | Q <sub>max</sub> | p <sub>0</sub> | p <sub>max</sub> | Zτ       |
|---------------------------------------------|-----------|-------------------|------------------|----------------|------------------|----------|
| Baseline radial load                        | 1.50 MN   | 1.00              | 109.5 kN         | 0.997 GPa      | 0.997 GPa        | 0.606 mm |
| Bladed Fyz,max                              | 1.9346 MN | 1.00              | 141.2 kN         | 1.132 GPa      | 1.132 GPa        | 0.688 mm |
| Bladed Fyz,max +<br>moderate edge loading   | 1.9346 MN | 1.35              | 141.2 kN         | 1.132 GPa      | 1.528 GPa        | 0.688 mm |
| Rating radial load + strong<br>edge loading | 2.266 MN  | 1.50              | 165.4 kN         | 1.225 GPa      | 1.838 GPa        | 0.745 mm |