Compensation Factor for Bone Core Sensor Calibration in 3-Point Bending

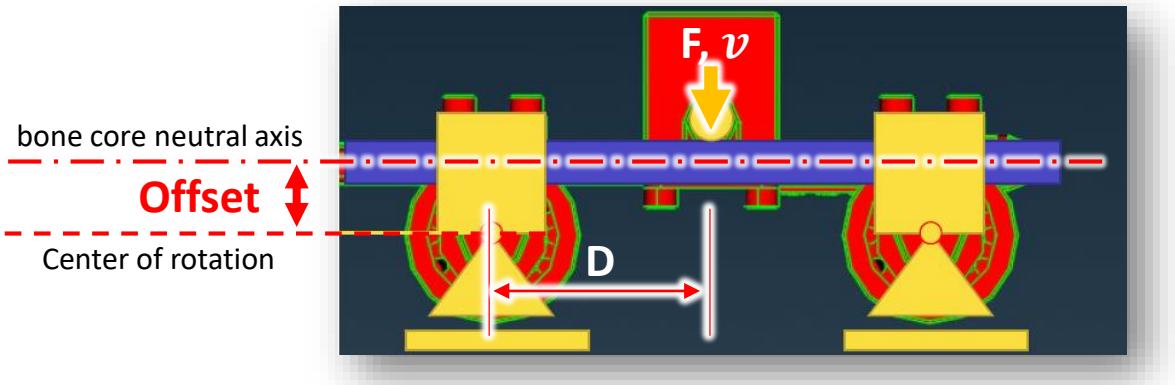
10/13/2022

ISO TC22/SC36/WG5&WG6/aPLI Task Group

3-pt Bending Test Configuration for Bone Core Certification

Test Method

3-point bending with eccentric support



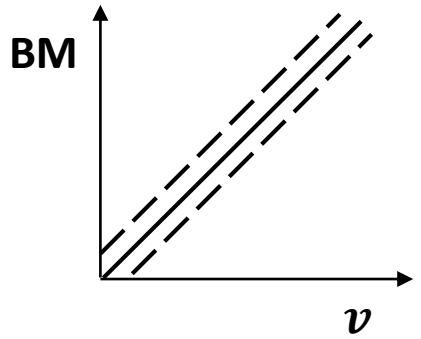
where,
F: Applied force
v: deflection
D: Half of span length
BM: Bending moment

BM = F/2 × D

Test data

Certification Corridor

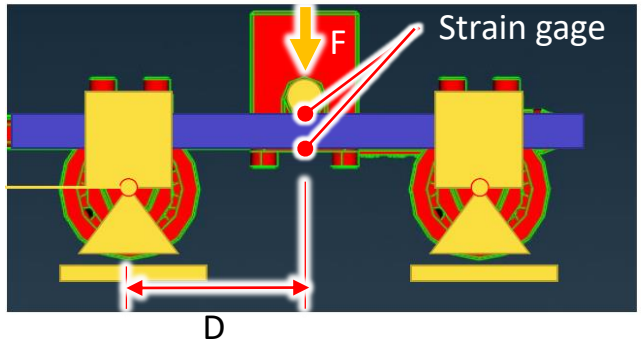
Corridor (developed based on master leg test data)
Test data for certification



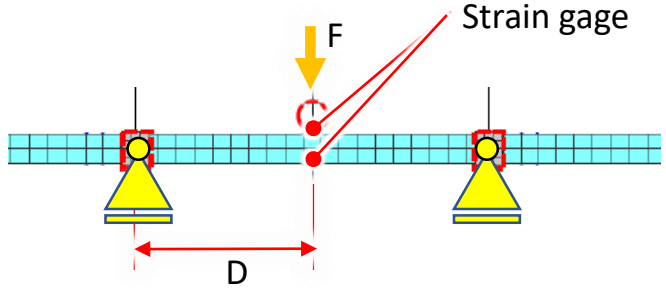
- **3-pt bending test rig** the bone core certification is **with an offset of the center of rotation** of the simple support fixture from the neutral axis of the bone core
- **This does not influence the certification** of the bone core as the boundary and test conditions are clearly defined in the ISO TS 20458 and certification corridor was developed based on the test data obtained using this test configuration

Bone Core Sensor Calibration

Test configuration with offset



Test configuration without offset



$BM_1 = F/2 \times D$

Difference?

$BM_2 = F/2 \times D$

- In case the same test configuration is used to determine the BM/strain conversion factor and the bending moment is calculated by multiplying the applied force by the half span length, then **the offset would influence the conversion factor**
- ISO TC22/SC36/WG5&WG6/aPLI Task Group has investigated the influence by means of theoretical and numerical analysis to **derive a compensation factor** to the conversion factors determined by the method described above

Methodology to Derive Compensation Factors

Theoretical analysis

- ✓ Beam theory
- ✓ Moment-strain response in 3-point bending of the bone cores (femur, tibia) **with an offset**, with the moment calculated from **the applied force and the span length**
- ✓ Moment-strain response in 3-point bending of the bone cores (femur, tibia) **without an offset**, with the moment calculated from **the beam theory**

FE analysis

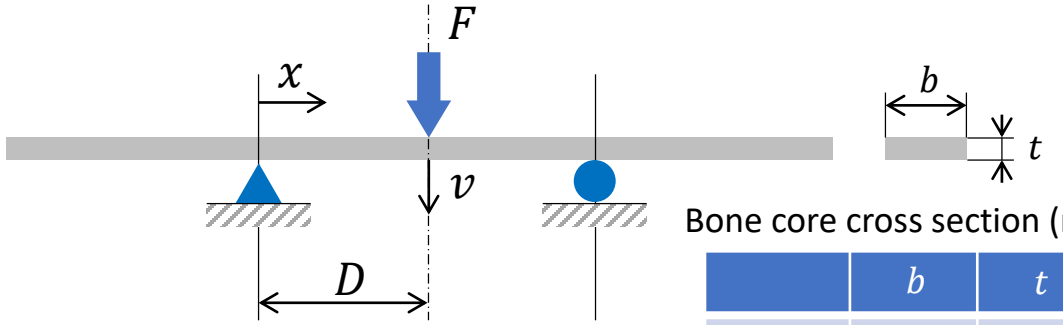
- ✓ FE models of the femur and tibia bone cores
- ✓ Moment-strain response in 3-point bending of the bone cores (femur, tibia) **with an offset**, with the moment calculated from **the applied force and the span length**
- ✓ Moment-strain response in 3-point bending of the bone cores (femur, tibia) **without an offset**, with the moment obtained by **the section moment**

Moment range

- ✓ Tibia: 420 Nm (FlexPLI relaxation zone threshold + margin), Femur: 545 Nm (converted from tibia using section modulus)

Theoretical Analysis

- **Without offset** : simply supported condition



Bone core cross section (mm)

	b	t
Femur	49	10.4
Tibia	40	10.2

D : half span length (65 mm)
v : deflection
ϑ : deflection angle
E : elastic modulus (4.55E+10 (Pa) determined from FE analysis)
I : geometrical moment of inertia
ε : strain on the bottom surface

$$\frac{d^2v}{dx^2} = \frac{d\vartheta}{dx} = -\frac{M(x)}{EI} \qquad 0 \le x \le D: M(x) = \frac{F}{2}x$$

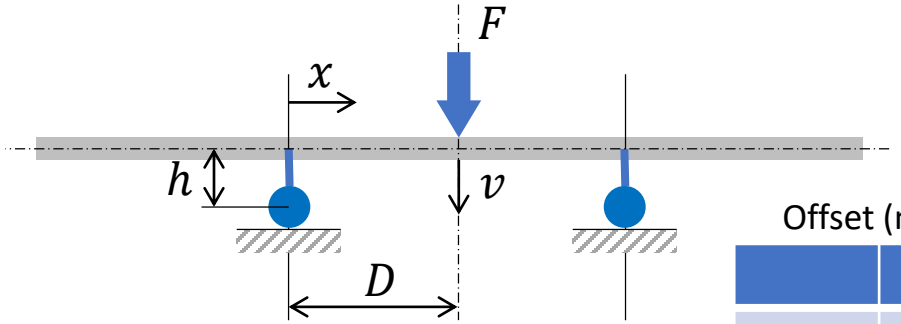
$$v(0) = 0, \quad \vartheta(D) = 0$$

$$\vartheta(x) = \frac{F}{4EI}(D^2 - x^2)$$

$$v(x) = \frac{F}{12EI}x(3D^2 - x^2)$$

$$\varepsilon = \frac{Mt}{2EI}$$

- **With offset** : test condition



Offset (mm)

	h
Femur	20.7
Tibia	20.6

$$0 \le x \le D: M(x) = \frac{F}{2}x + \frac{F^2D^2h}{4(2EI - FDh)}$$

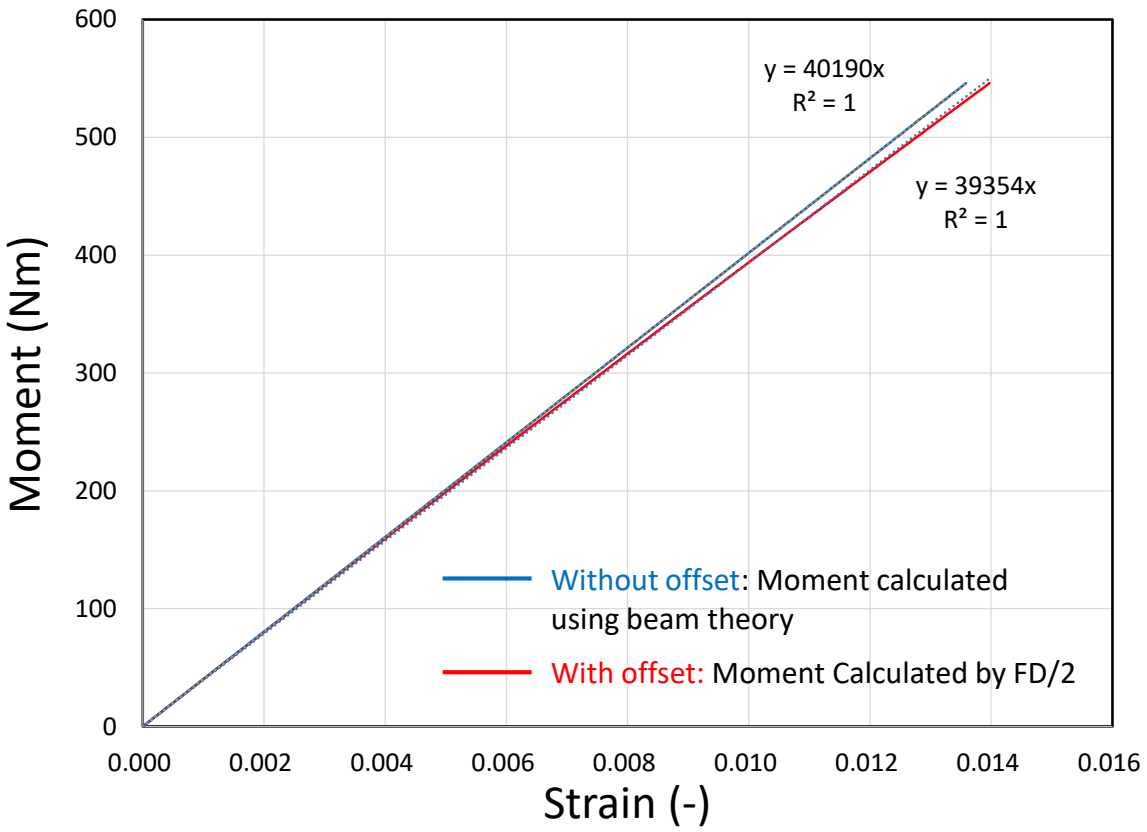
$$M(0) = \frac{F}{2}h\vartheta(0), \quad \vartheta(D) = 0$$

$$\vartheta(x) = -\frac{F}{4EI}x^2 - \frac{F^2D^2h}{4EI(2EI - FDh)}x + \frac{FD^2}{2(2EI - FDh)}$$

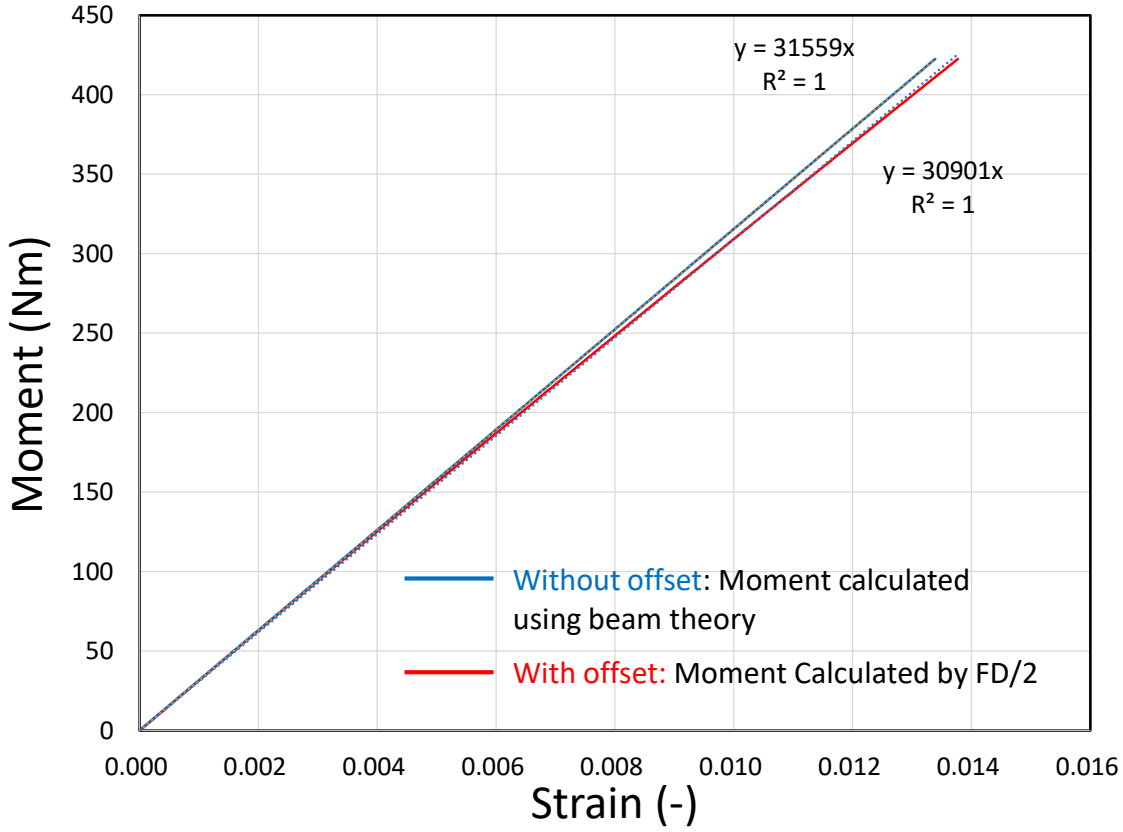
$$v(x) = -\frac{F}{12EI}x^3 - \frac{F^2D^2h}{8EI(2EI - FDh)}x^2 + \frac{FD^2}{2(2EI - FDh)}x$$

Theoretical Analysis

Femur



Tibia

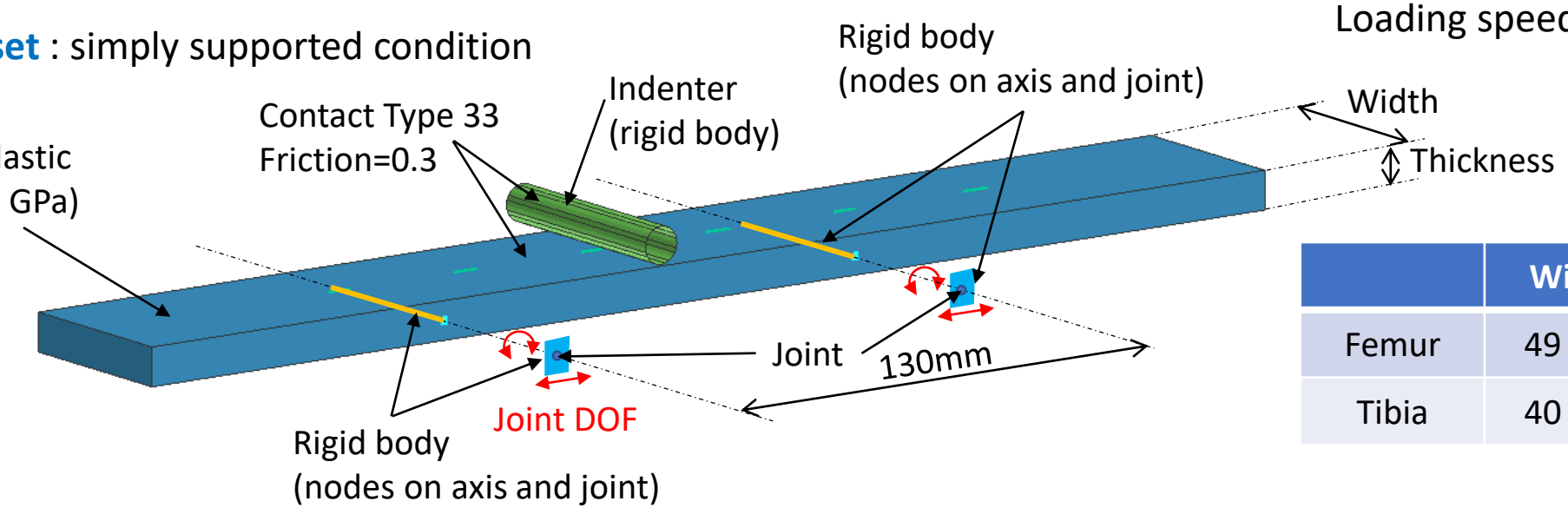


Bone	Moment/Strain (Nm)		Compensation Factor
	WO Offset	W/Offset	
Femur	40190	39354	2.12 %
Tibia	31559	30901	2.13 %

FE Analysis

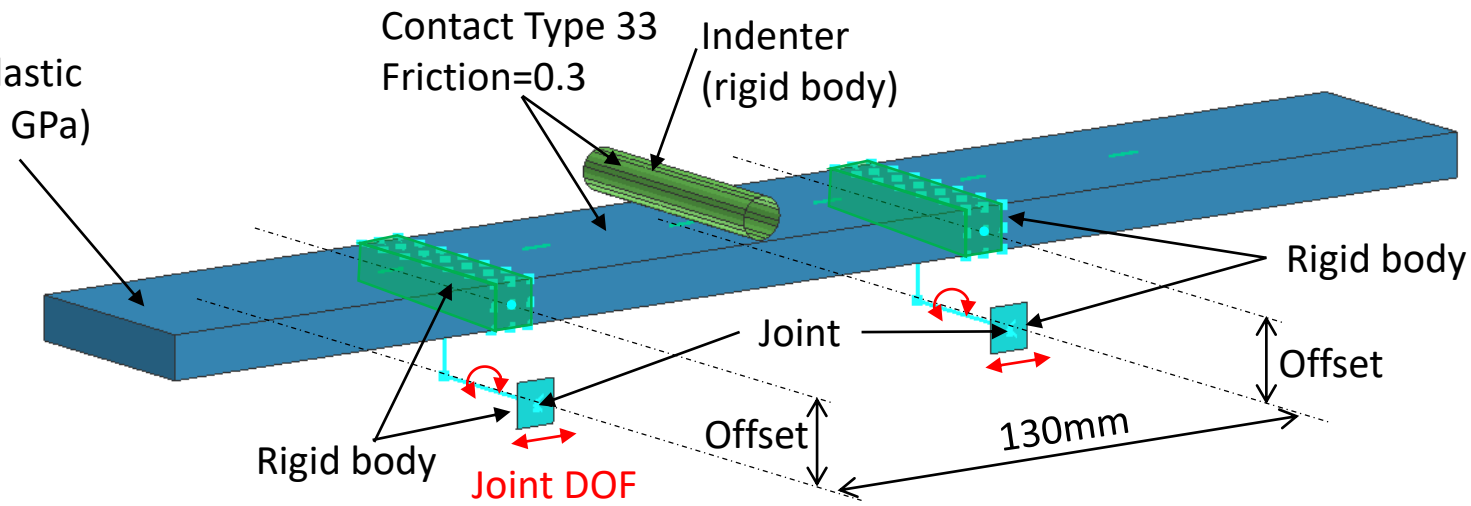
Solver: PAM-CRASH Ver. 2010
Loading speed: 1 mm/s

- **Without offset** : simply supported condition



	Width	Thickness
Femur	49 mm	10.4 mm
Tibia	40 mm	10.2 mm

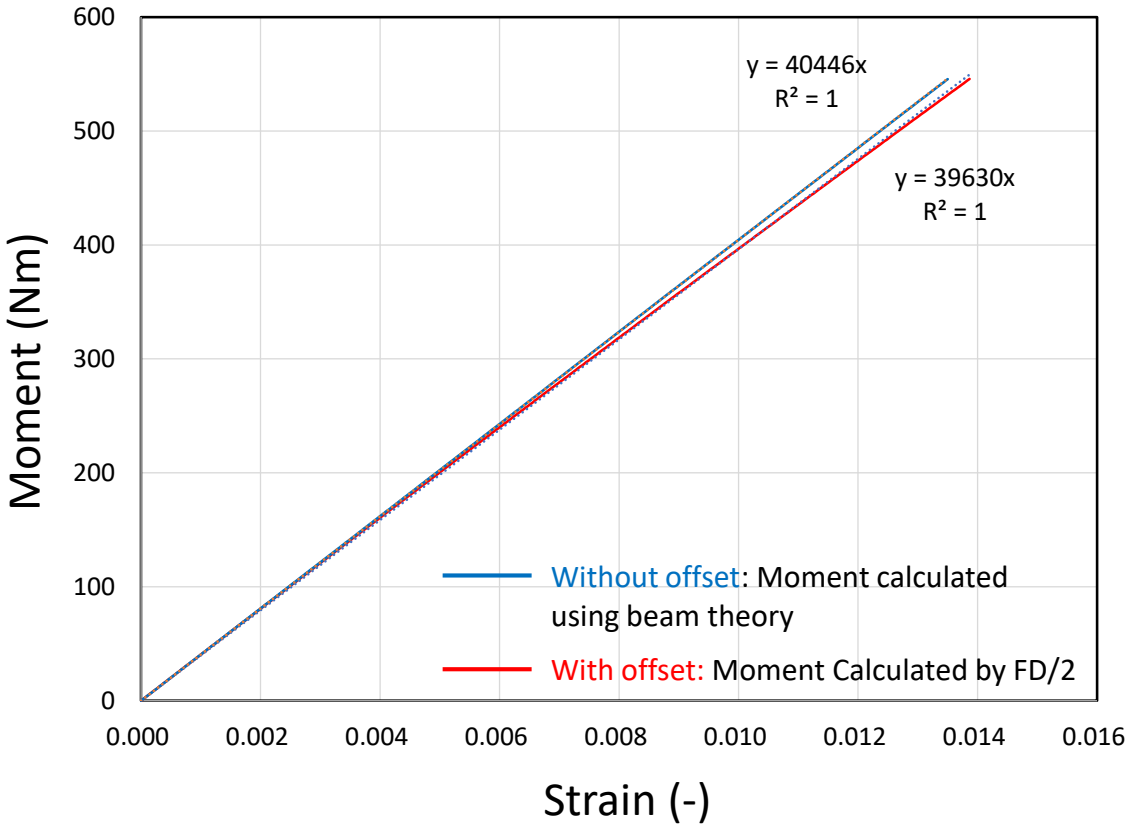
- **With offset** : test condition



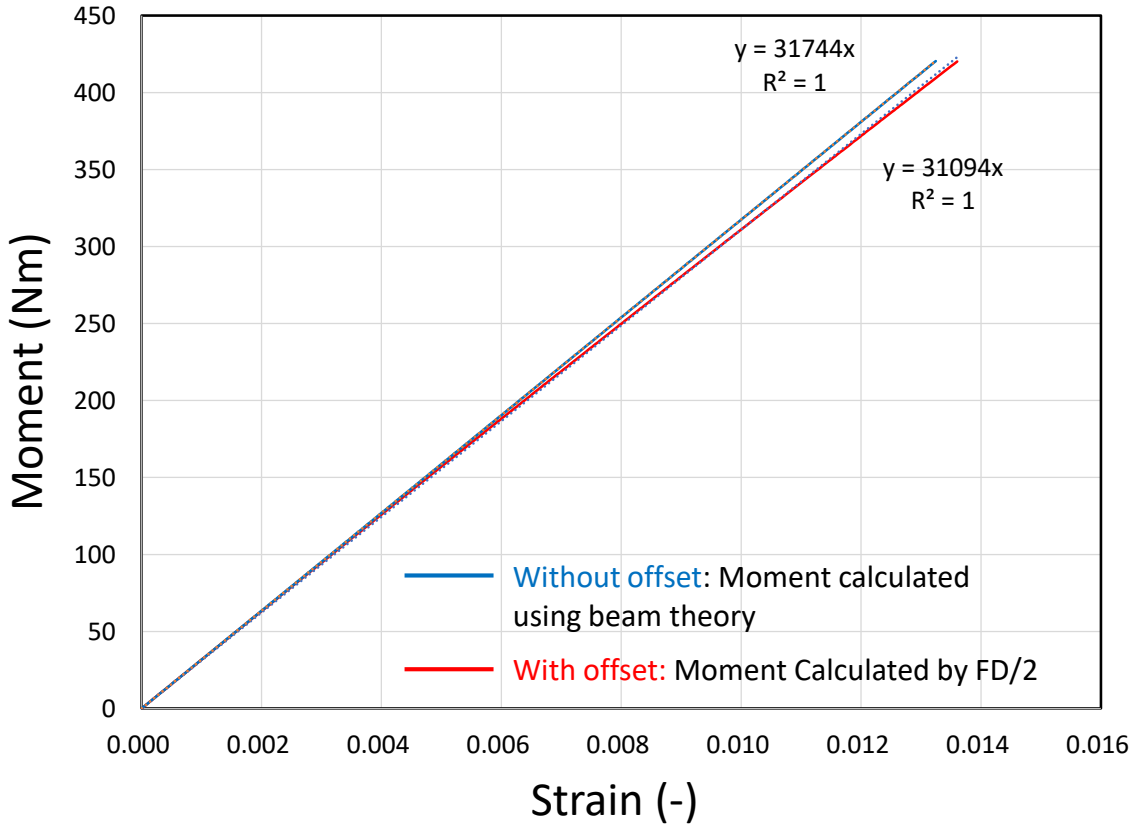
	Offset
Femur	20.7 mm
Tibia	20.6 mm

FE Analysis

Femur



Tibia



Bone	Moment/Strain (Nm)		Compensation Factor
	WO Offset	W/Offset	
Femur	40446	39630	2.06 %
Tibia	31744	31094	2.09 %

Summary and Recommendations

- aPLI Task Group simulated **3-point bending of the aPLI bone cores with and without an offset** of the center of rotation of the simple support fixture from the neutral axis by means of both **theoretical analysis and FE simulation**
- As **both analyses resulted in the same number**, it was proposed to use the compensation factor of **2.1% (for both femur and tibia bone core)**, which was agreed by the experts of aPLI Task Group
- The compensation factor has been **applied to relevant data** described in the **draft version of the ISO TS 20458**
- aPLI Task Group has also **recommended aPLI manufacturers to use the compensation factor of 2.1%** when they use the 3-point bending test rig with an offset for sensor calibration, and to **notify existing users of the updated BM/strain conversion factors**
- **It is highly recommended for existing aPLI users to contact the manufacturer** to see if past data need to be compensated, and to clarify appropriate conversion factor to be used for each individual hardware unit