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Threshold determination for neutral axis tracking based damage detection in wind-turbine towers

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Introduction

Wind Energy is seen as one of the most promising solutions to man's ever increasing demands of a clean source of energy. But there is a need to reduce the high initial costs for setting up and reducing the maintenance costs. The maintenance cost may be lowered through the use of structural health monitoring (SHM). SHM allows early detection of damage and allows maintenance planning which reduces the cost.

In [1] the methodology for the use of NA location as a damage indicator was proposed. The papers [2] used the methodology for the detection in presence of the yawing of the nacelle. In both these papers the alarm for the detection of damage was based on engineering judgment. But as in case of inspection based damage detection the engineering judgment is based on the skill of the individual and as a result is highly subjective. So, in this paper a sensitivity studies for the selection of the thresholds for damage detection are presented.

Objectives

- Sensitivity studies for the selection of the Kalman Filter parameters to ensure low false alarms and early damage detection
- Studying the effect of the location of damage to the delay in damage detection
- Studying the effect of the severity of damage to the exceeding of threshold

Theoretical Background

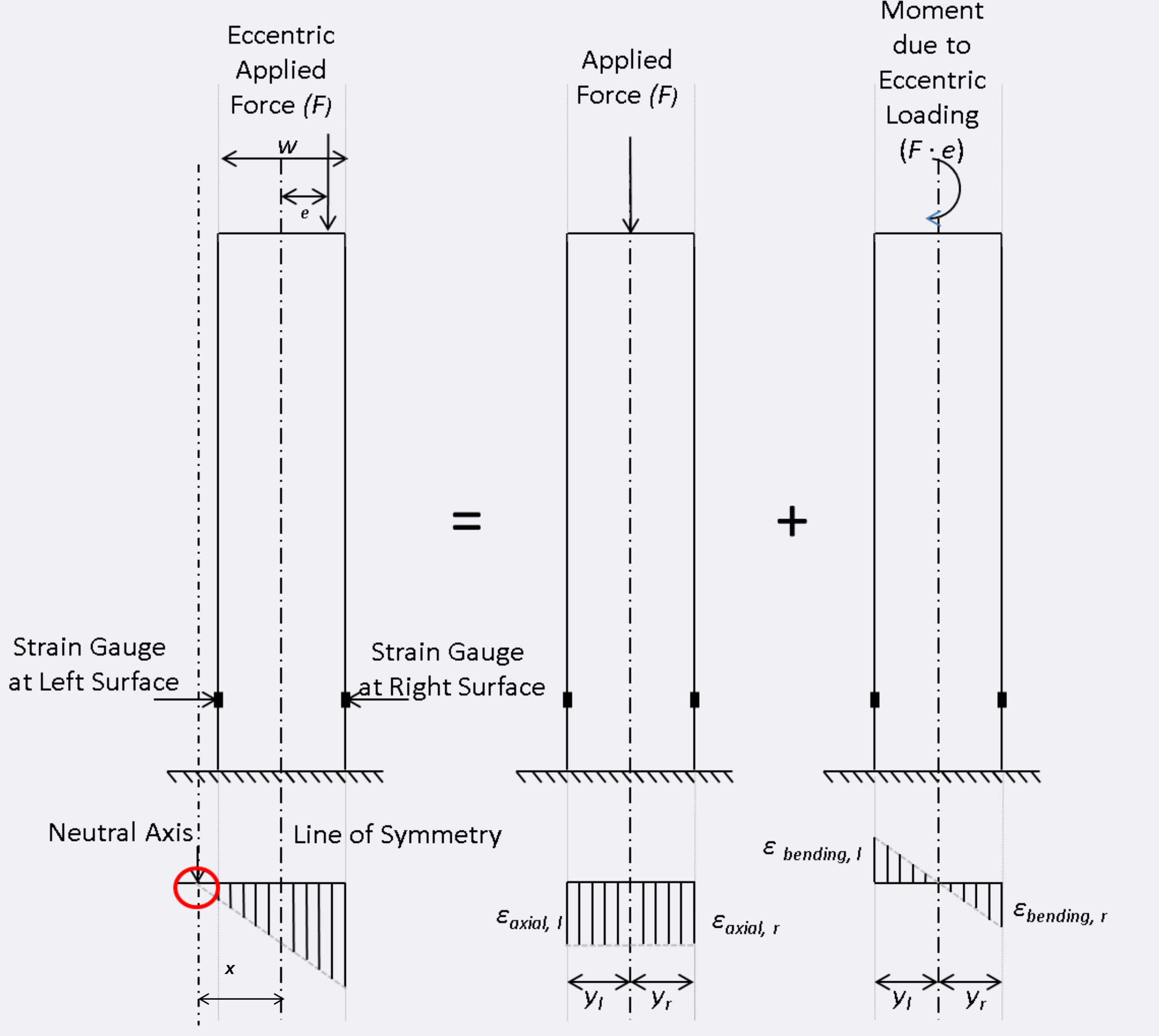


Figure 1: Flexural Strain Distribution over the beam cross-section [2]

$$NA\ location\ (x) = -\frac{\varepsilon_{axial} \cdot w}{2\ .\ \varepsilon_{bending}}$$

$$NA\ Estimate\ (NAE) = \frac{2\ .\ x}{w}$$

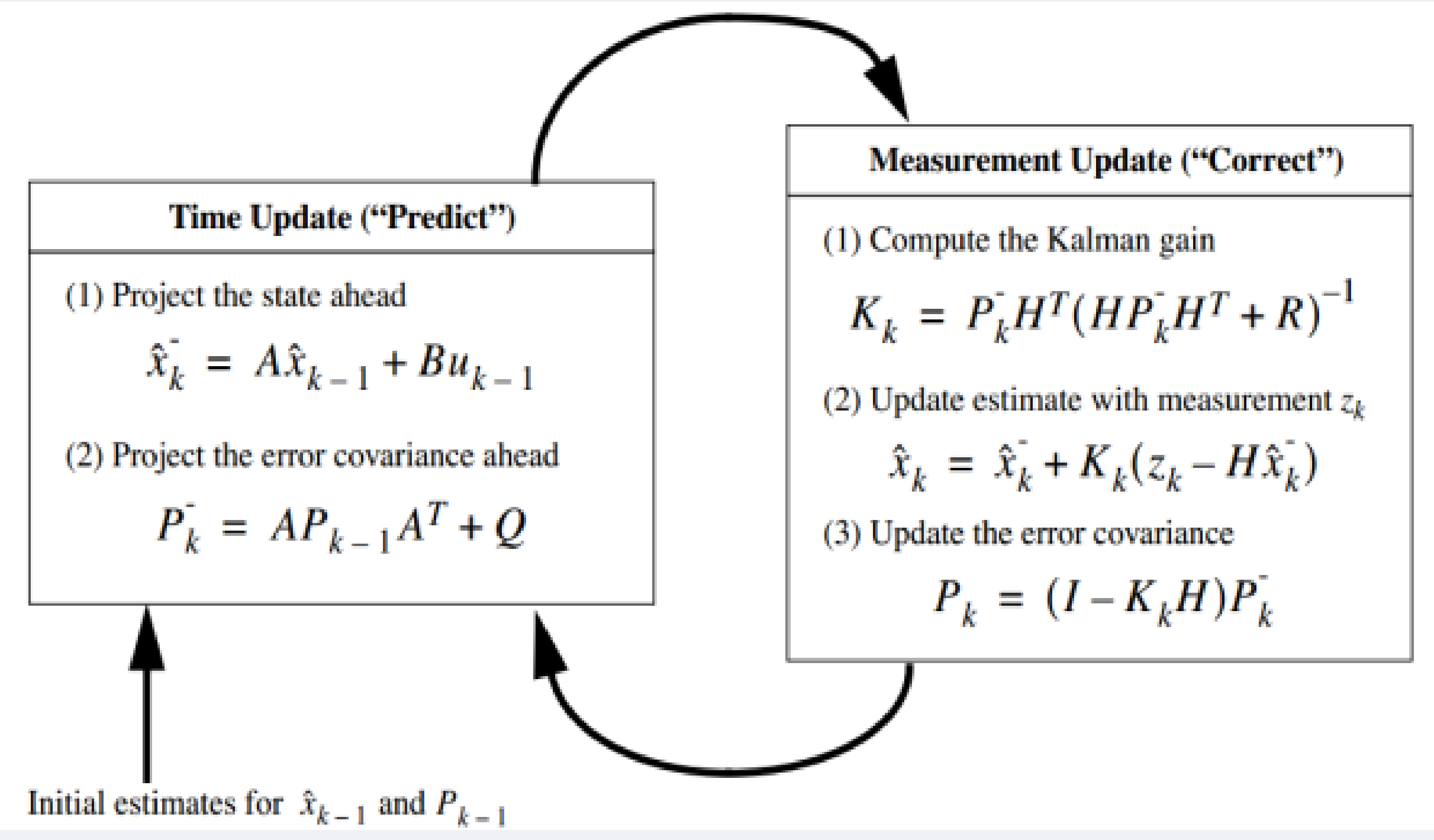
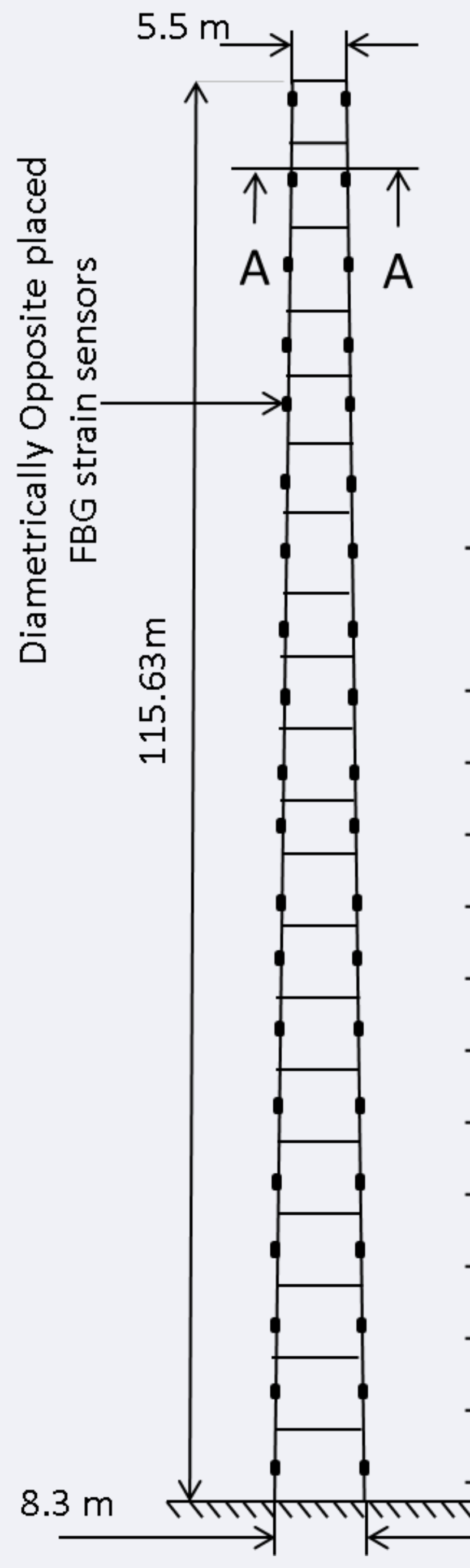
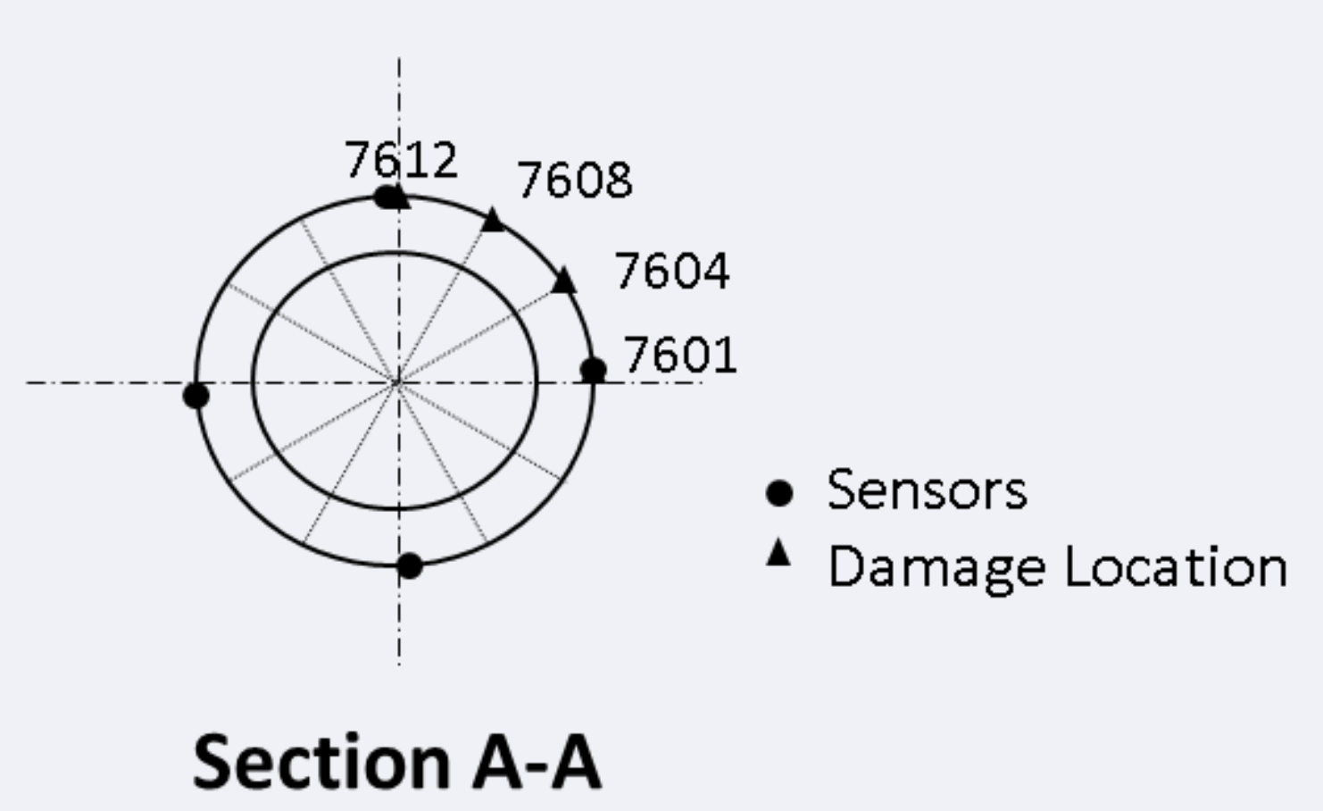


Figure 2: Flow Chart for the implementation of the KF [3]

where, x is the estimate of the state, A is the state transition matrix, B is the control matrix, u is the control variable, P is the state variance matrix, Q is the process variance matrix, K is the Kalman gain, H is the measurement matrix, z is the measurement variable, the 'super minus' indicates a priori estimate while the subscripted k indicates the time step.

Finite Element Modelling





Height (m)	Outer Diameter (m)	Thickness (mm)
0	8.3	38
11.5	8.015	36
23	7.743	34
34.5	7.484	32
45	7.186	30
57.5	6.908	28
69	6.629	26
80.5	6.351	24
92	6.072	22
103.5	5.795	20
115.6	5.5	20

Figure 3: FE modelling details of Tower

The tower was modelled with shell elements, as indicated from [4].

Damage was introduced by reducing the flexural rigidity of the element with damage

The tower was subjected to wind loads random in magnitude and direction as computed from [5]

Results

- **Sensitivity of NA Estimate to KF parameters**

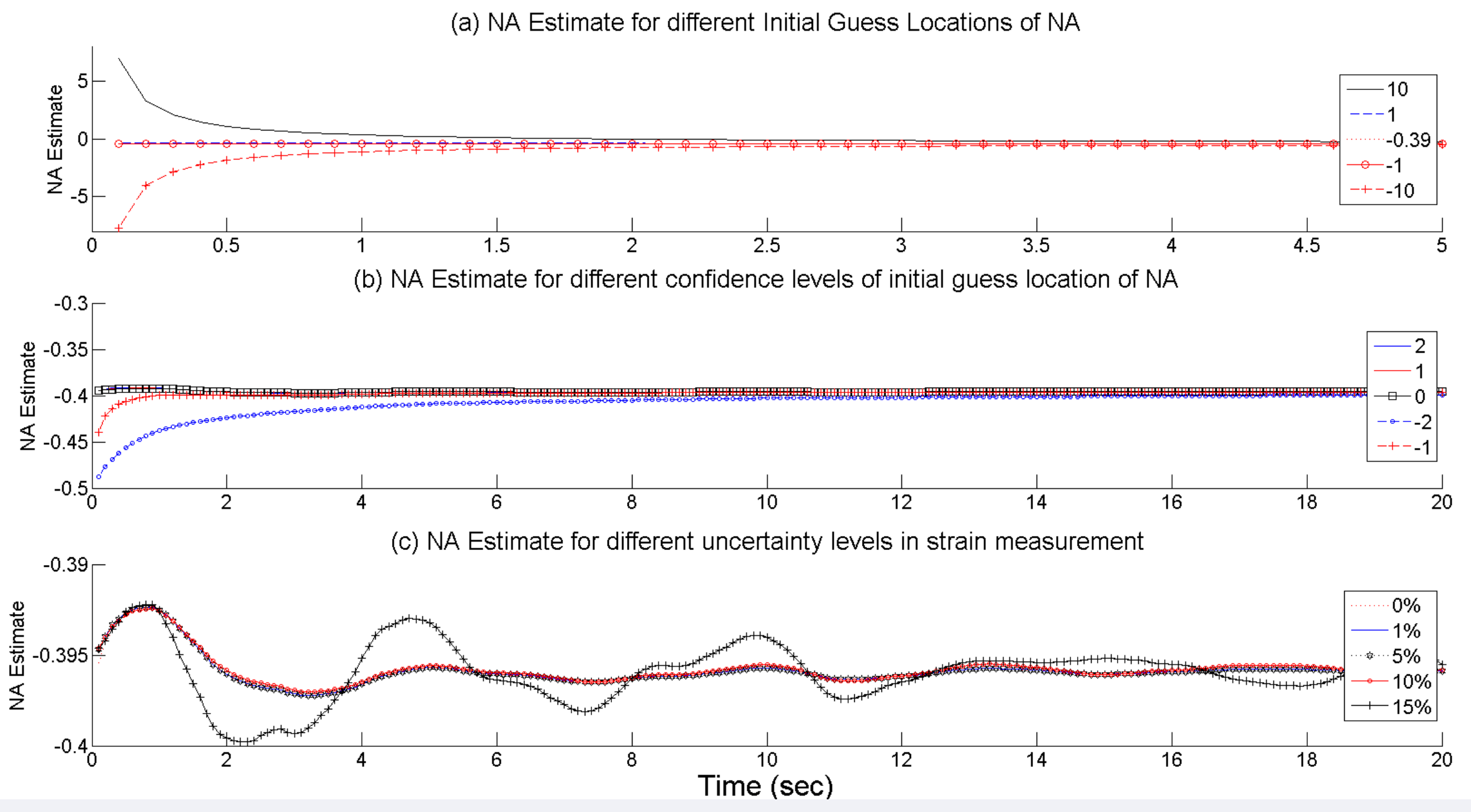


Figure 4: Sensitivity of NAE to KF parameters

The figure 4a shows the independence of the final NA estimate to the initial guess position of the NA estimate. The estimate converges to the true position within a short time and as such the damage detection algorithm is not affected

The figure 4b shows the independence of the final NA estimate to the uncertainty in the initial guess position given by the state variance matrix. This value influences the rate at which convergence is achieved and in the case of continuous long term monitoring will not affect the tracking of NA

The figure 4c shows the effect of uncertainty in the strain measurements to the NA called as the measurement noise. More the measurement noise more unsteady the NA Estimate, which in turn will affect the threshold values for damage detection

Several damage scenarios were simulated in order to select the threshold value for damage detection.

- **Threshold value selection for damage detection**

In Figure 5, 25% reduction of flexural rigidity was introduced at different locations. The change in NAE was then plotted with 2 different thresholds for damage detection. It can be seen that the higher the threshold, higher is the time delay between damage occurrence and the detection, also a higher threshold might lead to no detection namely location 7612 (Figure3).

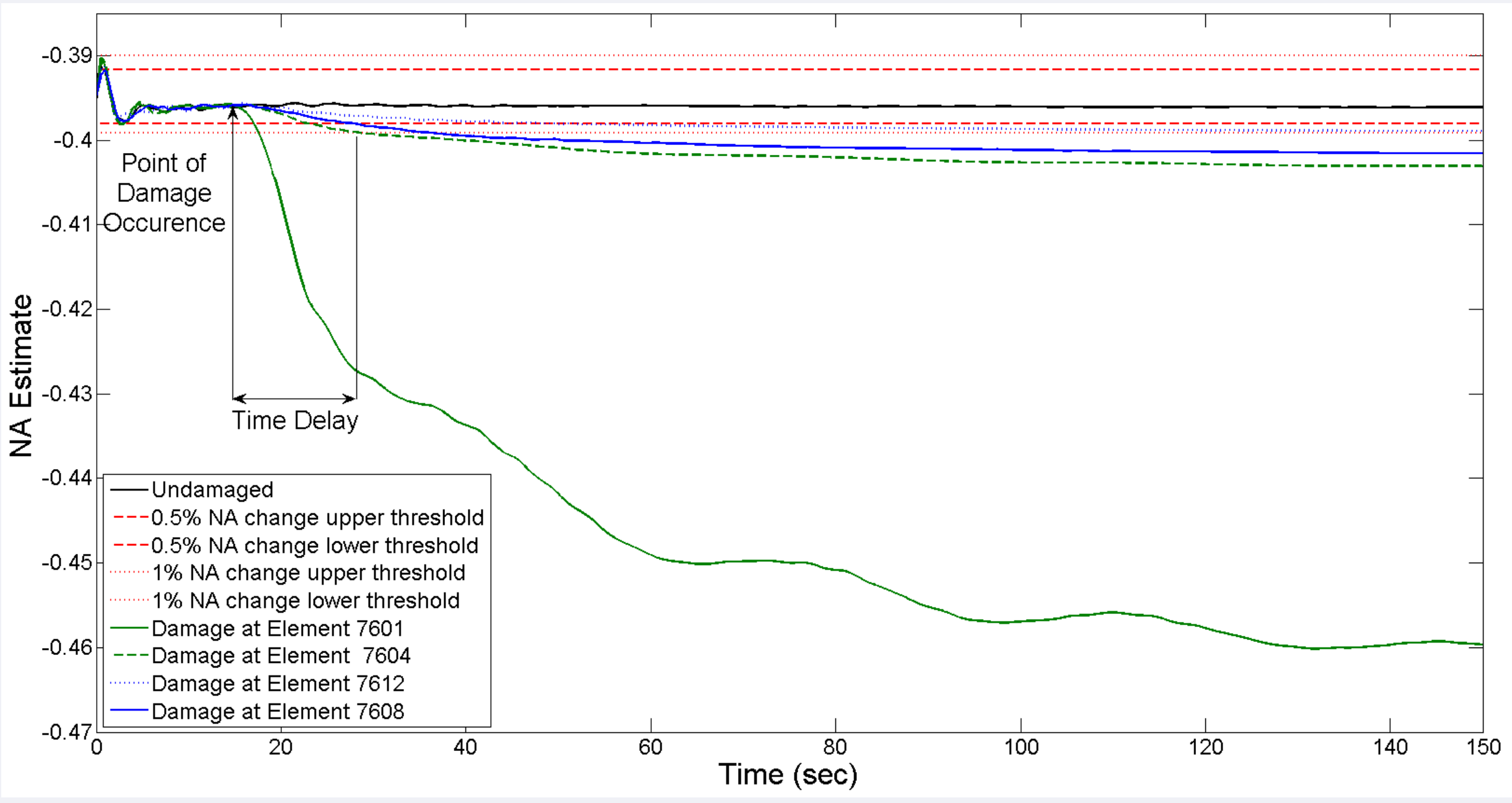


Figure 5: NA estimate for different locations of damage

A low threshold may lead to false positive detection as in the start of the plot. So there is a tradeoff between the false negative and false positive detection. In this case the value was chosen as 1% change in NA location.

The selected threshold does not allow detection of damage at location 7612, which is nearly perpendicular to the sensor and hence the observability of the cosine component of the change in NA is limited. But, this damage will be easily located by tracking the NA location using the complementary set of sensors.

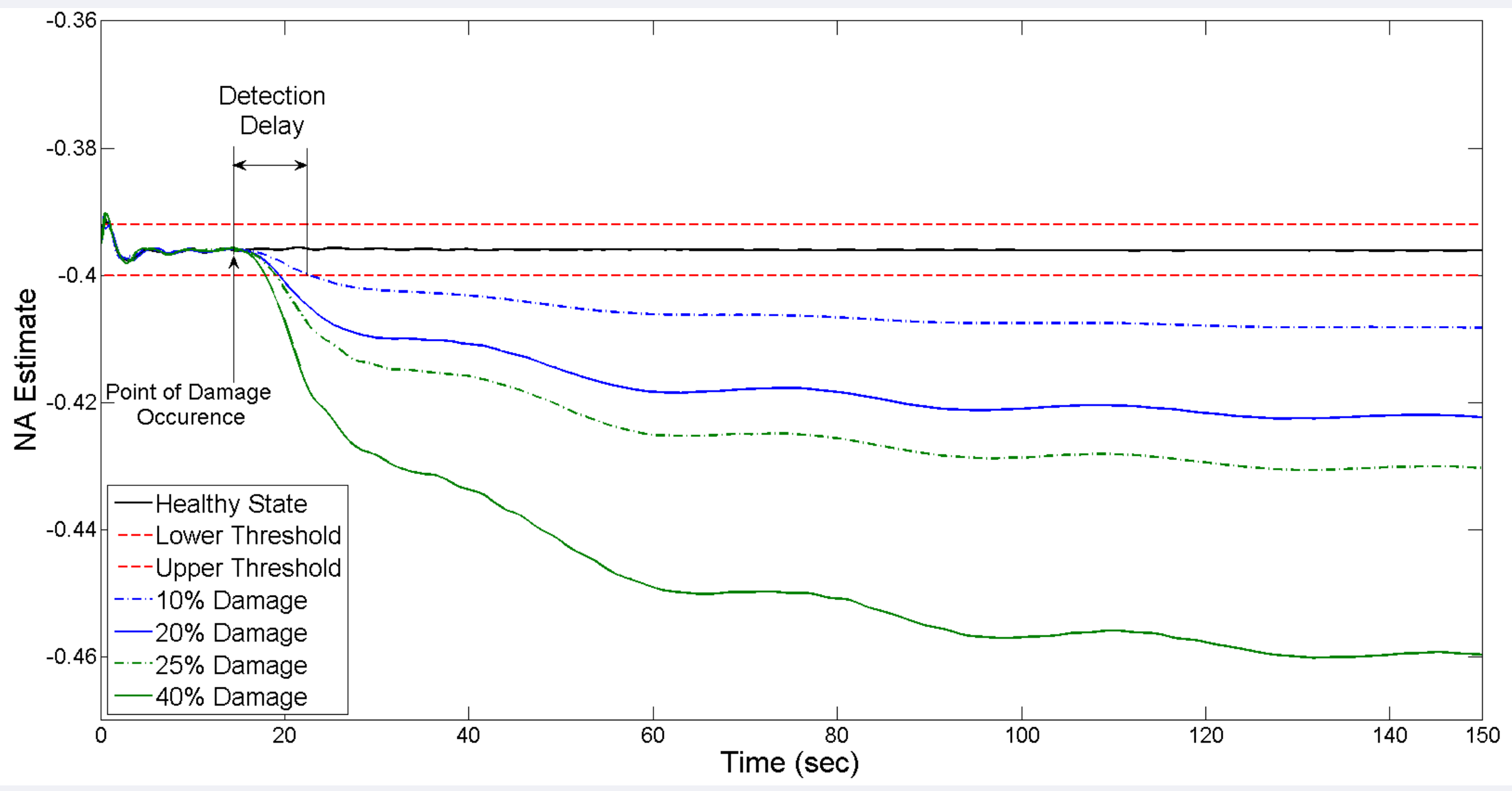


Figure 6: NA estimate for different levels of damage

Figure 6 shows the detection of damage for the case of damage at element 7601 for threshold 1% change in NA location. It can be seen that even 10% reduction in flexural rigidity is detected.

Conclusions

- The NAE is a robust parameter unaffected by the initial KF parameters
- The threshold selection is a tradeoff between false negative and false positive damage detection. A suitable value is selected based on the acceptable delay between damage occurrence and detection. The level selected in 1 % change in NAE location which reduces the probability of false positive detection to 0, and delay for detection less than 30 seconds.

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