# Spring Selection Tool (SST): README and Startup Guide

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## Nomenclature

$k_i$ Stiffness of individual spring $i$ [$\mathrm{N\,m^{-1}}$]

$k_{\mathrm{parallel}}$ Equivalent stiffness of springs in parallel [$\mathrm{N\,m^{-1}}$]

$k_{\mathrm{series}}$ Equivalent stiffness of springs in series [$\mathrm{N\,m^{-1}}$]

$N$ Number of springs in arrangement

$\epsilon$ Percentage error between the target and output stiffness of SST candidate

$F_0$ Initial force [N]

$F_n$ Maximum load at $L_n$ [N]

$L_0$ Unloaded length of spring [m]

$L_n$ Maximum loaded length of spring [m]

$R$ Spring constant (spring rate, stiffness) [$\mathrm{N\,mm^{-1}}$]

$S_n$ Maximum travel of spring [m]

# 1 Introduction

The **Spring Selection Tool (SST)** is designed to assist in selecting appropriate spring configurations to represent the scaled elasticity of fibre mooring lines in tank testing of offshore renewable energy (ORE) devices. By automating the search through extensive spring catalogues, the SST helps users quickly identify arrangements that match target stiffness values while balancing practical considerations such as availability, procurement, and ease of installation.

# 2 Spring Selection Tool (SST)

## 2.1 Quick Start

To run the SST:

1. Prepare your mooring parameters (see Table 2).
2. Launch the SST app.
3. Input the parameters when prompted.
4. Review the plotted results and the ranked configuration table.
5. Select the most appropriate spring configuration, balancing stiffness accuracy and practicality.

For a full description of equations, selection criteria, and workflow, refer to Section 2.

## 2.2 Tool architecture

The SST is designed to be both versatile and flexible, accommodating different mooring inputs while remaining efficient and accessible to any wave basin facility. Its two objectives are:

1. minimise the error between the target axial stiffness and the mechanical stiffness of the selected spring system; and
2. minimise the total number of springs to reduce tank model complexity and procurement challenges.

The spring arrangements are analogous to capacitive electrical circuits (Childs, 2021), as illustrated in Figure 1, with stiffness calculated using Equations (1) and (2).

$$\frac{1}{k_{series}} = \sum_{i=1}^{N} \frac{1}{k_i} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + ... + \frac{1}{k_n} \tag{1}$$

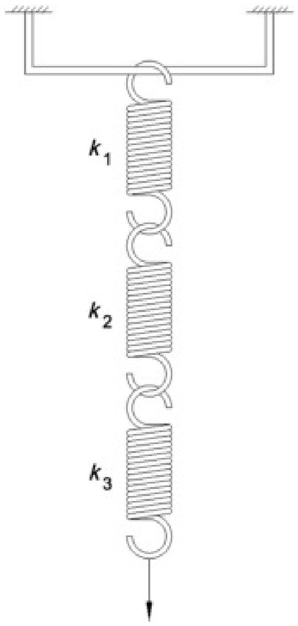
$$k_{parallel} = \sum_{i=1}^{N} k_i = k_1 + k_2 + k_3 + ... + k_n \tag{2}$$

## 2.3 Spring parameters

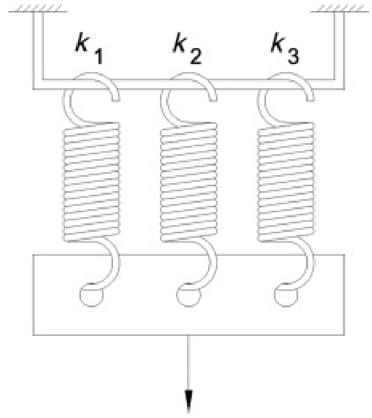
The spring parameters for the catalogues are given in Table 1.

## 2.4 User inputs

The user input for the tool are described in Table 2. Its likely better to be conservative in the choice of maximum inputs, especially when survival testing is being done. The advantage of using springs is that their stiffness response is known and easy to replicate in a numerical model, however, that certainty is lost if the springs over-extend or are loaded beyond its limits.




(a) Springs in series.




(b) Springs in parallel.

Figure 1: Spring arrangements. Symbols relate to Equations (1) and (2). Reproduced from Childs (2021).

Table 1: Spring parameters.

| **Parameter** | **Symbol** | **Unit** |
|---|---|---|
| Material | - | - |
| Unloaded length | $L_0$ | mm |
| Maximum loaded length | $L_n$ | mm |
| Maximum travel | $S_n$ | mm |
| Maximum load at $L_n$ | $F_n$ | N |
| Initial force | $F_0$ | N |
| Spring rate | $R$ | $\mathrm{N\,mm^{-1}}$ |

Table 2: Glossary of full-scale user inputs for the Spring Selection Tool (SST).

| **Symbol** | **Description** | **Units** |
|---|---|---|
| $\lambda$ | Froude scaling factor. Used to convert inputs from full- to tank-scale. | – |
| $x_{\text{travel}}$ | Maximum expected travel of the floating body under environmental conditions. Ensures spring extension is sufficient. | m |
| $F_{\text{tension}}$ | Maximum expected mooring line tension under environmental conditions. Ensures the spring can withstand peak loading. | N |
| $F_{\text{pretension}}$ | Mooring line pretension in static equilibrium. Prevents spring breakout. | N |
| $EA$ | Rope axial stiffness. Used to calculate $k_{\text{mech}}$. | N |
| $L$ | Unstretched rope length. Used with $EA$ to calculate $k_{\text{mech}}$. | m |
| $k_{\text{mech}}$ | Target mechanical stiffness. Either user-defined or calculated as $EA/L$. | N/m |

### 2.5 Workflow

The automated workflow of the SST is outlined in Algorithm 1.

**Algorithm 1:** Spring Selection Tool (SST) workflow. User input symbols refer to Table 2.

**Input:** $\lambda$, $x_{\text{travel}}$, $F_{\text{tension}}$, $F_{\text{pretension}}$, and either $(EA, L)$ or $k_{\text{mech}}$
**Output:** Shortlisted spring configurations and plots
**Step 1: Initialisation**
**if** *User provides EA and L* **then**
  $k_{\text{mech}} = EA/L$
**else**
  Use user-provided $k_{\text{mech}}$
Scale inputs using $\lambda$; load spring catalogues.
**Step 2: Selection Loop**
Loop over possible parallel branches and series springs. For each arrangement:

1. Compute breakout force, maximum force, and maximum travel.
2. Filter out configurations that fail user constraints.
3. Calculate equivalent stiffness and error from target.
4. Store valid configurations.

**Step 3: Post-processing**
Score, rank, and shortlist configurations. Output scatter plot and table.

## 2.6 Outputs

The SST produces:

- a scatter plot showing stiffness error vs. spring count;
- a ranked table of configurations;
- a summary of both full-scale and scaled inputs.

### 2.6.1 Scatter plot interpretation

The SST produces a scatter plot (e.g., Figure 2) showing all shortlisted spring arrangements against:

- **X-axis:** stiffness error ($\epsilon$) from the target value,
- **Y-axis:** total number of springs in the arrangement ($N$).

Each candidate is plotted as a marker, colour-graded so that the most attractive arrangements (low stiffness error and few springs) appear prominent, while less suitable arrangements fade into the background.

The legend symbols highlight:

- $\star$ = **Optimal solution(s)** – best compromise of low stiffness error and few springs (lowest score from Algorithm 1).
- $\times$ = **Lowest-error solution(s)** – minimum stiffness error regardless of spring count.
- $+$ = **Fewest-springs solution(s)** – minimum $N$ regardless of stiffness error.
- $\bigcirc$ = **In-stock solution(s)** – available in tank stock.
- $\cdot$ = Other valid solutions.

**How to use the plot:**

1. First, check the ⋆ markers – these usually offer the best practical trade-off.
2. If absolute accuracy is critical, consider the × markers, but note they may require many springs (and therefore be harder to source or install).
3. If simplicity and ease of procurement are priorities, the + markers may be preferable, even if the stiffness error is slightly higher.

For example, in Figure 2, the lowest-error solution (×) has 18 springs per mooring line, which would require sourcing and installing 54 springs for a three-line system. In most cases, the ⋆ solution will be more practical for testing programmes.

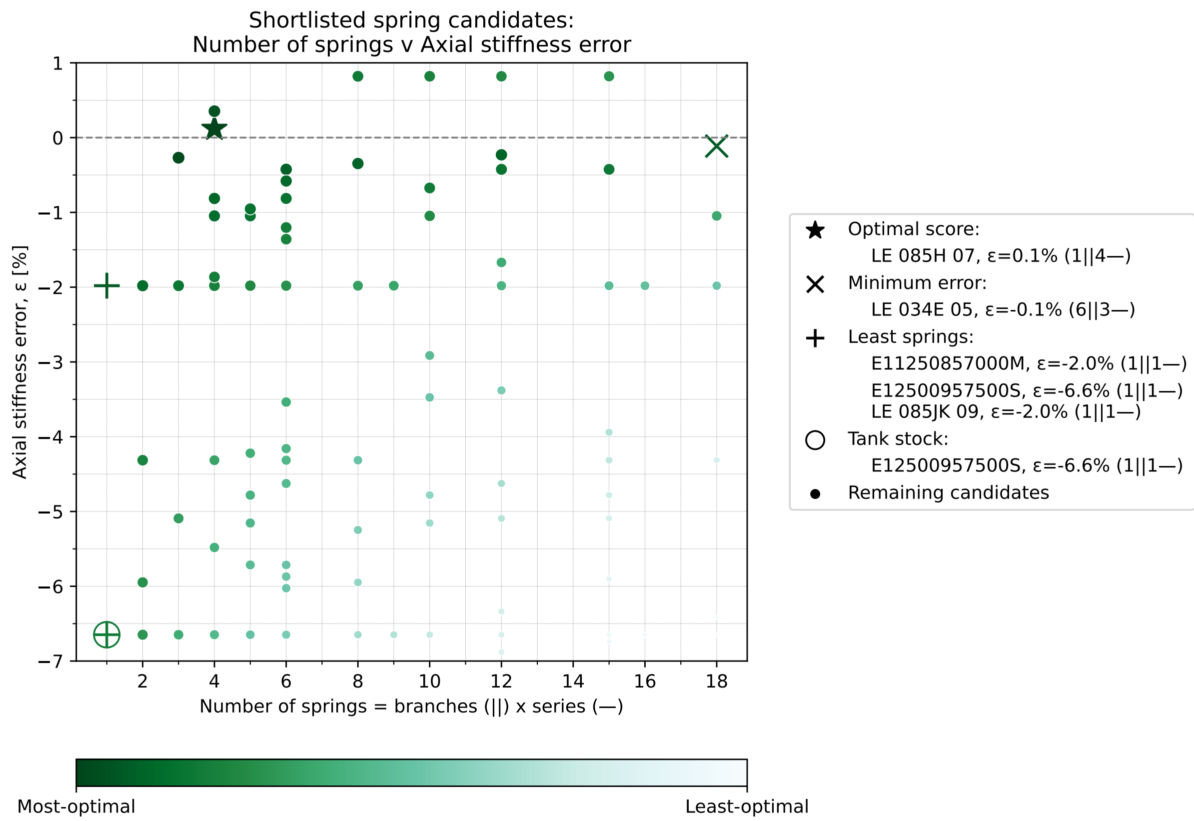



Figure 2: Example SST scatter plot. The most optimal arrangements are highlighted, while suboptimal candidates fade into the background.

## 2.7 Spring rate uncertainty propagation

In practice, springs are supplied with a manufacturer's stiffness tolerance (e.g., ±10%). When springs are arranged in series or parallel, the overall uncertainty in the system stiffness can be estimated using the *propagation of uncertainty* method (Beckwith and Marangoni, 2006).

### 2.7.1 Propagation formula

For a function $f$ of several independent variables $(x, y, z, \dots)$, the relative uncertainty is:

$$\frac{\delta f}{f} = \frac{1}{f}\sqrt{\left(\frac{\partial f}{\partial x}\cdot \delta x\right)^2 + \left(\frac{\partial f}{\partial y}\cdot \delta y\right)^2 + \left(\frac{\partial f}{\partial z}\cdot \delta z\right)^2} \tag{3}$$

Here:

- $x, y, z$ = stiffness values of each individual spring $(k_1, k_2, k_3, \dots)$,
- $f$ = equivalent stiffness of the arrangement (either $k_{\text{series}}$ from Equation (1) or $k_{\text{parallel}}$ from Equation (2)),
- $\delta x, \delta y, \delta z$ = uncertainties in each spring's stiffness.

#### 2.7.2 Worked example

Suppose each spring has:

- Spring rate $R = 0.03\ \mathrm{kN\,mm^{-1}} \pm 10\%$,
- Maximum load $F_n = 16.30\ \mathrm{N} \pm 10\%$,
- Initial load $F_0 = 1.48\ \mathrm{N}$,
- Travel $S_n = 407.92\ \mathrm{mm}$.

Arrange them as two parallel branches, each with three springs in series. Applying Equation (3), the system stiffness uncertainty is ±12.3%, equivalent to a range of:

$$0.02631 \text{ to } 0.03369\ \mathrm{kN\,mm^{-1}}.$$

#### 2.7.3 Direct calculation check

Alternatively, the spring rate can be calculated directly from:

$$R = \frac{F_n - F_0}{S_n} \tag{4}$$

If $F_n$ is varied by ±10%, this gives a maximum spring rate of $0.04033\ \mathrm{kN\,mm^{-1}}$. This is higher than the propagated uncertainty result, likely due to rounding in catalogue values.

#### 2.7.4 Uncertainty factors

For quick reference, Figure 3 shows the *multiplication factors* for converting a single-spring stiffness tolerance into a total system tolerance. For example, in the above arrangement, the factor is 1.22, giving:

$$\text{System tolerance} = 1.22 \times 10\% = 12.3\%.$$

While the plot gives a good quick estimate for calibration planning, as the uncertainty analysis using Equation (4) showed, the actual maximum spring rate of the system may be higher due to rounding.

## References

Thomas Beckwith and Roy Marangoni. *Mechanical Measurements*. Pearson, 6th edition, 2006. ISBN 9780201847659.

P.R.N. Childs. Chapter 9 - Springs. In *Mechanical Design*, chapter 9, pages 337–370. Butterworth-Heinemann, 2021. ISBN 978-0-12-821102-1. doi: 10.1016/B978-0-12-821102-1.00009-3.

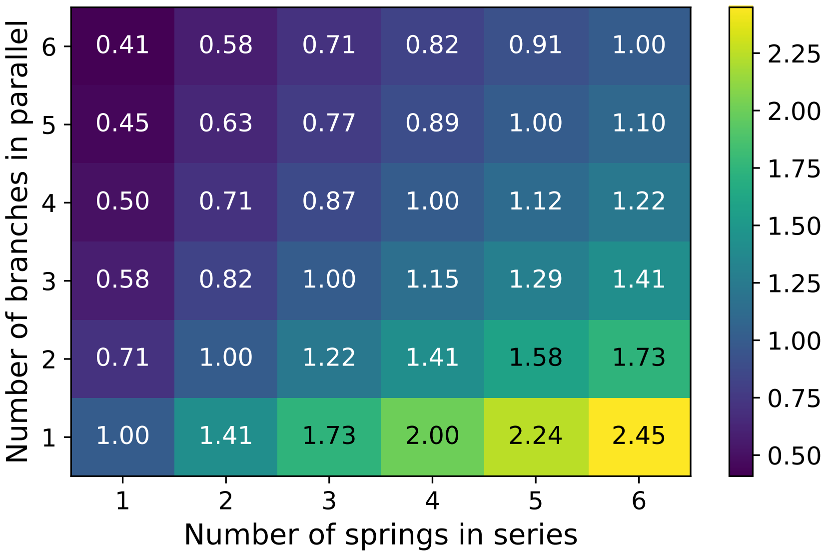



Figure 3: Multiplication factors for converting individual spring rate tolerance to total arrangement stiffness tolerance.