ICOE INTERNATIONAL CONFERENCE ON OCEAN ENERGY
OCEAN ENERGY EUROPE
Donostia - San Sebastián 2022

Reducing uncertainty in WEC extreme load estimates via Goodness-of-Fit testing

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INTRODUCTION

Structural failure occurs when stress at a specific location exceeds the local material resistance capacity. As stress is typically associated with a loading regime, the strength of a structural component can be related to an **Ultimate Limit State (ULS)** load that causes such failure.

For systems subject to multiple combinations of environmental conditions and / or machine states, such as Wave Energy Converters (WECs), the ULS load can be defined as the highest of the **extreme loads**. As WECs are most often subject to a stochastic environmental loading, extreme loads are typically evaluated by adopting **reliability-based** design approaches.

For example, IEC/TS 62600-2 [1] requires a WEC to achieve a Safety Level (SL) of 2, which corresponds to being designed to withstand a load which may statistically occur at least once every 50-years. However, [1] provides little practical guidance on how to derive estimates of 50-year return period load(s), and **visual inspection** is often used to select a suitable extreme value distribution that yields the long-term return load(s).

The methodology developed in this work draws on existing best practices to suggest a novel, **practical** method to assess the suitability of specific **extreme value distributions** for the estimation of extreme loads in the design of offshore structures. The proposed method is based on the use of **goodness-of-Fit (GoF)** tests [2].

METHOD

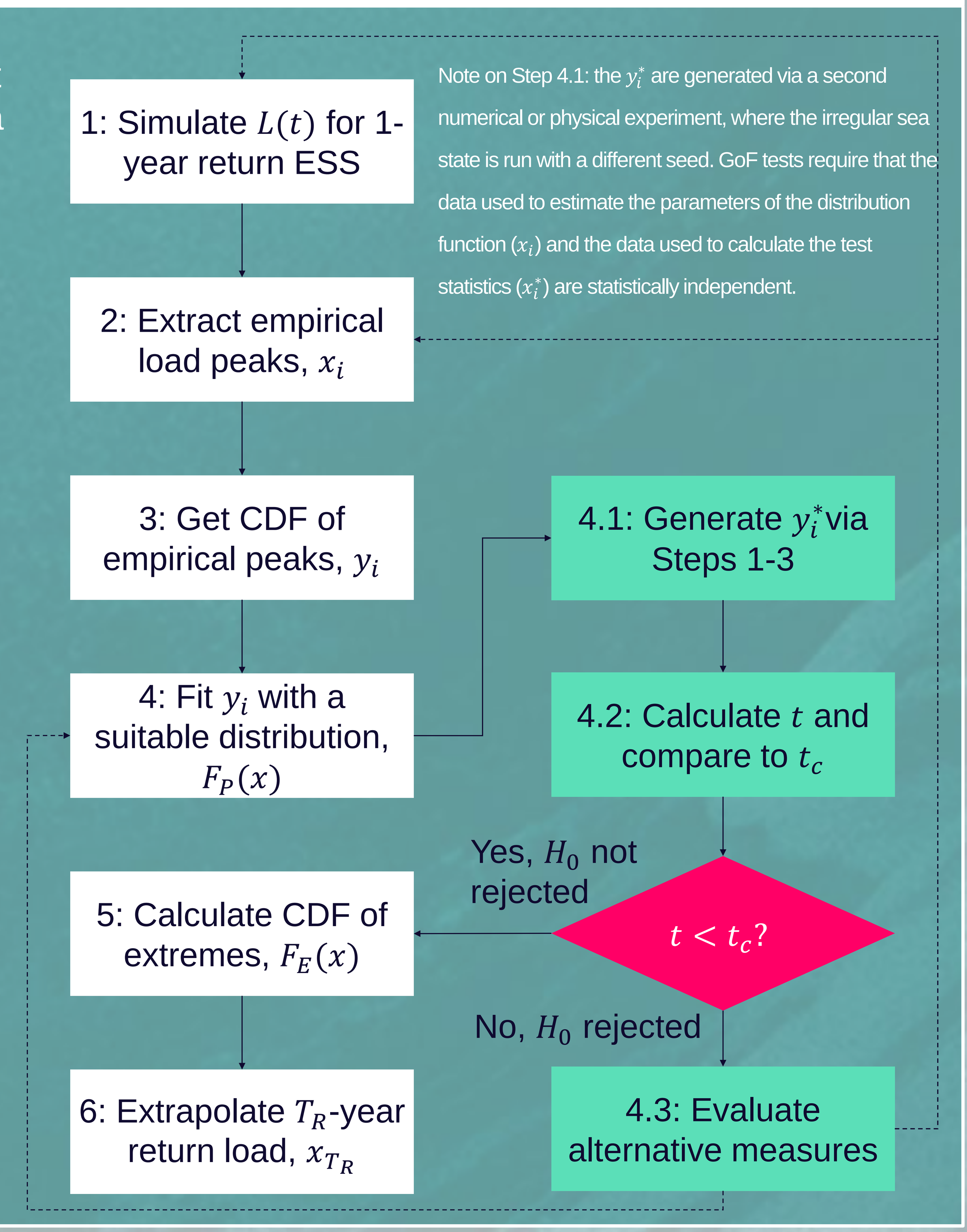
Goodness-of-fit tests can be used to test the **hypothesis** (referred to as H_0) that a data sample comes from a specific distribution.

In this work, goodness-of-fit tests were used to assess whether a population of load peaks, x, belongs to a specific distribution, $F_P(x)$ – Weibull (WEI), Weibull Tail-Fit (WTF), Gumbel (GUM), Generalised Pareto (GP), Generalised Extreme Value (GEV).

Typically, a test statistic t is calculated and compared against a **critical value**, t_c (associated with a given significance level). Whenever $t > t_c$, the hypothesis H_0 is rejected and there is no **evidence** that the empirical data come from the selected distribution.

Four different goodness-of-fit tests were assessed:

- Kolmogorov-Smirnov (D).
- Kuiper (V).
- Cramer – Von Mises (W^2).
- Anderson-Darling (A^2).



RESULTS AND KEY FINDINGS

Figure 1

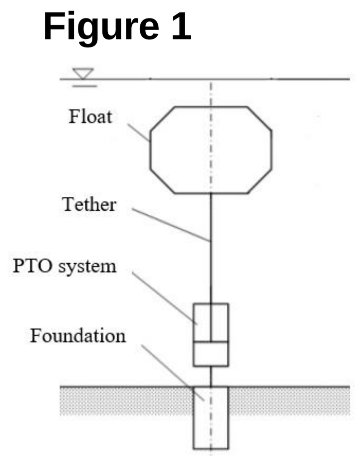


Figure 2

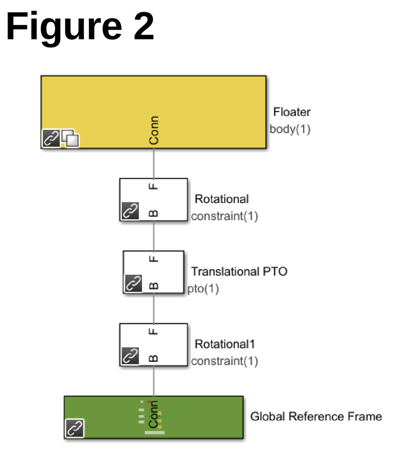


Figure 3

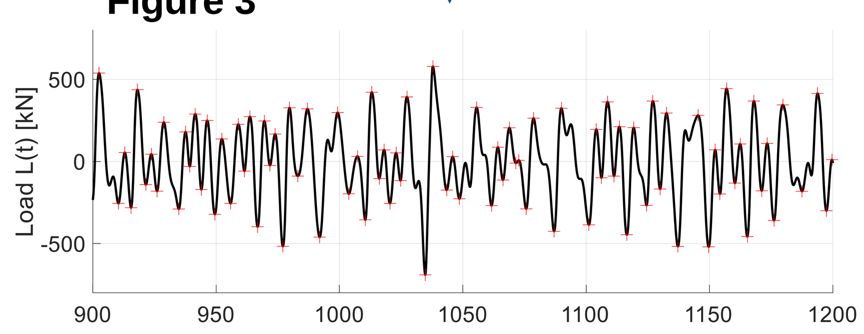


Figure 4

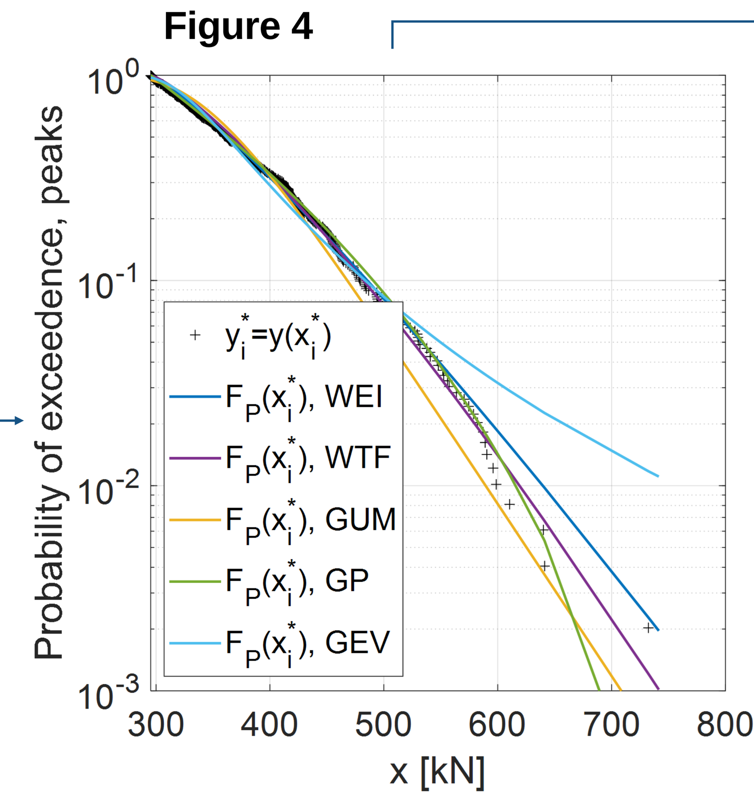


Figure 5

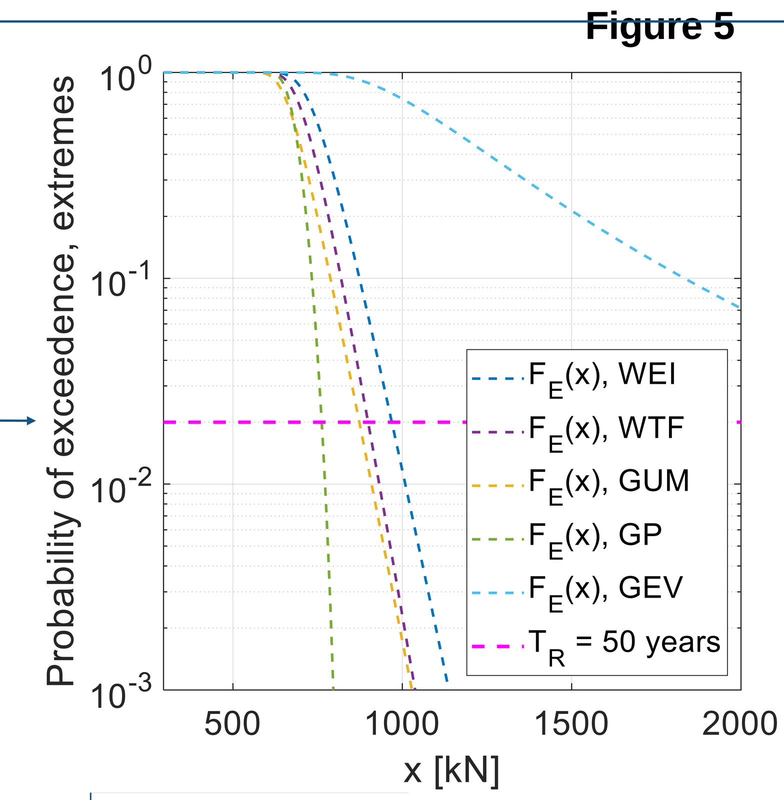


Table 1

x_{50} [kN]	WEI	WTF	GUM	GP	GEV
	969	899	873	762	2,779

Table 2

$F_P(x)$	D	V	W^2	A^2
WEI	0.822	1.476	0.136	1.480
WTF	1.323	1.802	0.510	4.439
GUM	1.951	3.103	0.983	6.220
GP	0.509	0.836	0.034	0.396
GEV	1.337	2.572	0.487	3.580

- Point Absorber WEC conceptualized (Fig. 1) and modelled in WEC-Sim (Fig. 2).
- Time-series of vertical load at the foundation generated for a 1-year return sea state (Fig. 3, black line).
- Positive and negative peaks extracted from the load time-series (Fig. 3, red crosses).

- Empirical CDF of load peaks fitted with several distributions (WEI, WTF, GUM, GP, GEV – Fig. 4).
- Extremes distributions subsequently derived (Fig. 5), together with 50-year return loads (x_{50}, Table 1).
- **Different distributions may lead to very different extreme load estimates.**
- **Peaks are not extremes (and should not be confused).**

- Grey cells indicate test statistics which exceeds the critical value (Table 2).
- The GEV and GUM distribution are rejected by most (if not all) tests – in line with what a visual inspection would have concluded.
- All tests but Kolmogorov-Smirnov reject the hypothesis that the load peaks come from a WTF distribution – while the fit appears (visually) reasonable.
- The WEI and GP distributions are not rejected by any test, and GP consistently leads to the lowest test statistic estimates. This promotes GP as the most suitable distribution for this case.
- **Visual inspection may have led to choosing WTF and thus a 50-year return load ~27% higher than that estimated by GP.**

ACKNOWLEDGEMENT

The proposed methodology was developed within the VALID project (EU H2020 GA No 101006927). The reference data used was generated within the IMPACT project (EU H2020 GA No 101007071).

REFERENCES

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[2] D'Agostino, R.B., Stephens, M.A. (1986). Goodness-of-fit techniques. M. Dekker, New York.