Evolutionary Structural Engineering: AI-Driven Dynamic Load Combinations for Sustainable Design

1 Introduction

In the realm of structural engineering, the conventional approach to load combinations for designing structures has long been rooted in the combination of specific actions with their absolute maximum design loads. However, a fundamental flaw lies beneath this traditional method—a paradox where these absolute maximum loads of various actions seldom coincide in reality. In other words, it is very unlikely to observe absolute maximum loads of different actions take place simultaneously. Consequently, when designers adhere strictly to these conventional design load combinations as per relative specifications, structures to be designed according to combination of actions that may never encountered during the service life of the structure.

In response to this challenge, this essay explores a design approach that defies traditional norms with the support of data collection and AI integration to analyse the collected data. It advocates the combination of concurrent effects based on their probabilities of simultaneous occurrence. This shift is driven by the integration of Artificial Intelligence (AI), which, with time, accumulates data on various sources of actions, allowing it to interpret their interactions.

By harnessing AI's capacity to collect, analyse, and forecast the interplay between different actions over a structure's lifespan, design engineers have the potential to optimize overall design loads on the structure. Thus, significant reductions in both material consumption and carbon emissions can be achieved. This will also be integrated with changes in environmental and social aspects as AI interprets the forecast between different actions by interpreting the tendency of the collected data in time. In the following sections, an assessment of the impact of these considerations on the field of structural engineering, including a forward-looking view of how Köhlbrand Bridge will be designed 30 years from now compared to past.

2 AI-Driven Structural Design Considerations for Dynamic Load Combinations

2.1 Location and Function-Based Design

Structural design specifications are comprehensive guides applicable to projects across wide geographical areas. Designers often adhere to these guidelines, emphasizing a conservative approach due to the impracticality of reinventing formulas for each project. However, in the pursuit of reduced material consumption and carbon emissions, determining design loads and their combinations takes on new significance.

In this phase, the structure's location becomes crucial, with various regions experiencing distinct environmental conditions. Traditionally, structural codes have called for the combination of maximum values for different load variables to determine the most challenging design load. Load factors in these codes depend on the possibility of load increase during the building's lifespan only.

While design standards remain fundamental, integrating AI allows for location-specific data analysis and design optimization based on real-world conditions, providing more sustainable design solutions.

AI-driven advancements in data collection and analysis introduce a pioneering aspect to this process. By examining concurrent effects based on real-time data collected in proximity to a construction site, designers can now consider location-specific influences during the design stage. For instance, mean wind speed on structures in Hamburg, Germany, illustrated in Figure 1. The data reveals that structures with heights below 150 meters experience maximum wind speeds during midday. Consequently, the minimum (absolute maximum) temperatures (observed at nighttime) need not be combined with the maximum wind speed load effects.

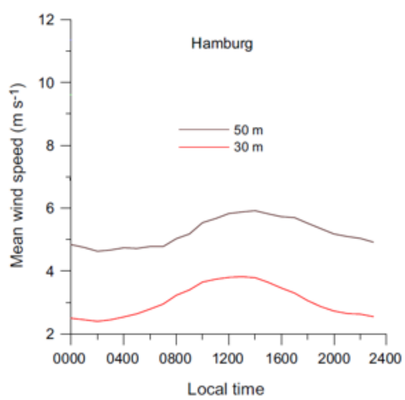

Figure 1 Mean Wind Speed Variation in Hamburg Across Different Structure Heights During the Day (Gryning et al., 2015)

Similarly, the likelihood of peak traffic loads is low during midday, coinciding with times outside of rush hours (Figure 2). In other words, design loads (absolute maximums) of different actions occur at different time frames for the same location. This underscores the opportunity to significantly reduce the overall (combined) design load by considering the occurrence of concurrent effects.

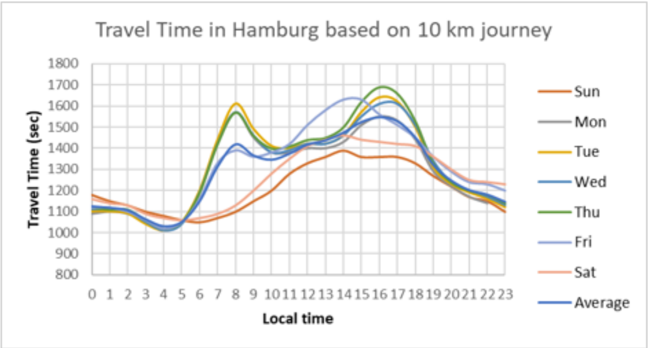

Figure 2 Traffic Live Load Interpretation Based on GPS Data (tomtom) - Hamburg, 2022 (10 km Limit)

Consideration of a structure's function also introduces a profound shift in design philosophy. Take, for instance, the numerous railway bridges in the UK, most of which remain inactive during nighttime hours when railway traffic is at its minimum. This period coincides with the time frame when other structural loadings may reach their peak values. Yet, traditional design practices combine absolute maximum values for all load effects, irrespective of their temporal characteristics.

2.2 Data Collection and Analysis for Load Sources

Building upon the examples given in the previous section, the source of actions must undergo meticulous monitoring, conducted both on an annual and daily basis. This data, diligently gathered from the vicinity of the structure, is utilized for the design of the structure after the combination of each variable conducted by AI.

Geographical variables such as wind patterns, temperature fluctuations, or snowfall are subjects of extensive monitoring. When it comes to dynamic live loads, Monitoring traffic load intensity per hour of the day, while accounting for future trends and social dynamics, is vital for comprehensive data analysis.

Finally, actions take place at the same time frame should be combined in contrary to envelope method of the conventional design approach. This shift away from conventional methods toward concurrent load combinations represents a significant move toward a more precise and optimized approach to structural engineering. The Köhlbrand Bridge in Hamburg was designed a half a century ago. What if it were designed 30 years later? It would likely appear far more delicate, featuring significantly reduced material consumption, all thanks to AI-driven concurrent force considerations.

Based on the design life of assets, AI can also interpret the trends of these effects. This becomes especially critical when considering emerging issues such as climate change, which directly impact the characteristics of abovementioned loads. For instance, as carbon dioxide levels rise and the Earth's poles warm, researchers predict a decline in the planet's wind speeds. This, in turn, affects surface temperature and even social trends that can be discerned from live loads. With a substantial amount of reliable data collected, the trends of these actions can be monitored, enabling the forecasting of future trends.

3 Conclusion

The integration of Artificial Intelligence (AI) into structural engineering presents a profound vision of the future where structures are designed with precise load data acquired through AI-driven advancements.

In this future, AI's ability to analyse and combine concurrent load effects leads to shift away from conventional design methods. Instead of merely considering maximum load values, structures can be optimized with remarkable efficiency. This optimization not only minimizes material consumption but also makes structures more environmentally sustainable.

Furthermore, AI's role as a constant observer and interpreter of load trends ensures that designs remain adaptable to evolving environmental challenges. As carbon emissions and climate-related issues take centre stage, AI empowers structural engineering to embrace sustainability as a guiding principle.