

## Adjustment and Calibration of Recent Shrink-Swell Volume Change Estimations for Pavement Covered Areas

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**Abstract:** This paper presents a calibration of the shrink-swell model prediction developed by Olaiz et al. (2021) for pavement covered areas. The model predicts volume changes in shrink-swell soils caused by environmentally induced changes in suction stresses in uncovered areas. To extend its application to pavements, the model was calibrated using pavement elevation change data from the Long-Term Pavement Performance (LTPP) database. Under the LTPP Seasonal Monitoring Program (SMP), deflection data at the pavement edges, from surface elevation and longitudinal profile measurements, were collected in the USA and Canada from 1993 to 2004 for both Asphalt Concrete (AC) and Portland Cement Concrete (PCC) pavements. Rod and level surveys were conducted to determine changes in pavement surface elevation over an average period of five years, at five different locations. The elevation changes at the pavement edge are assumed to be primarily influenced by climatic fluctuations. A total of 58 calibration points were used, comprising 41 from AC pavement sections and 17 from PCC sections. Given the stochastic nature of the model, the results of this calibration effort enable the incorporation of pavement distress caused by climatic and subgrade conditions into the roughness models available in the AASHTOWare Pavement Mechanistic-Empirical (ME) Design procedure.

### Introduction

The objective of this study is to adjust and calibrate the shrink-swell model developed by Olaiz et al. (2021) using elevation change data measured at pavement edges, where the influence of traffic is assumed to be relatively minimal. The prediction of relative movements in expansive soils is typically categorized into three approaches: oedometer-type laboratory testing, empirical or semi-empirical methods such as the Potential Vertical Rise (PVR), and suction-based methods. Studies have concluded that oedometer-type testing often overestimates in-situ heave [1], [2]. Empirical and semi-empirical methods rely on laboratory and field correlations that are specific to the samples used in the studies, making them less reliable for soils outside the range of calibration values. In contrast, suction-based methods allow for the prediction of

the heave and shrinkage of soil based on changes in moisture energy. Specifically, movement in shrink-swell soils is driven by changes in suction stress, which increases as soil moisture content decreases and vice versa [3].

A recently developed mechanistic-empirical model estimates volume-change in shrink-swell soils caused by climatic effects [4]. The model aims to provide a suitable alternative to the empirical Site Factor (SF) parameter, currently used in the AASHTOWare Pavement ME Design guide to evaluate distresses in the pavement due to problematic soil conditions such as high-volume change and frost susceptible soils. Deflection data at the pavement edges, collected as part of the LTPP database was used in the analysis. The data was statistically analyzed and the results were divided based on the pavement type into two groups: 1) AC pavements, which includes new AC pavements and AC overlays on flexible pavements, and 2) PCC pavements, which includes a) AC overlays of rigid pavements and semi-rigid pavements, b) jointed plain concrete pavement (JPCP), and c) continuously reinforced concrete pavement (CRCP). The calibration effort was based upon the premise that the statistical variability of the predicted volume changes can be directly correlated to the current International Roughness Index (IRI) solution methodology present in the AASHTOWare Pavement ME Design guide. This effort constitutes the first step of the critical calibration process.

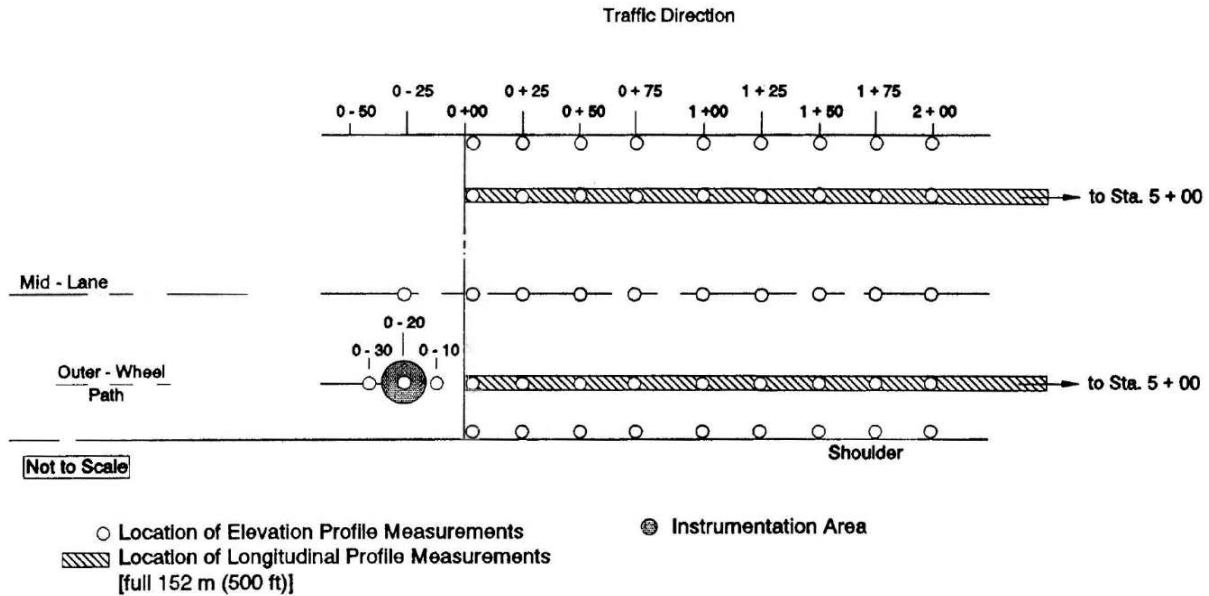
## **Database**

The LTPP database, which was used to collect the information needed for calibration, is the product of a large research program of data gathered from 2,000 pavement test sections over approximately a 20-year period. Data includes 1) subgrade material properties such as soil gradation from sieve analysis and hydrometer tests, Atterberg limits, water content, maximum dry density and optimum moisture content, etc., 2) climatic parameters such as annual average precipitation, temperature, freezing index, and relative humidity, 3) type of pavement, 4) pavement layers and thicknesses, 5) pavement distresses, and 6) IRI values measured overtime, among other information.

Part of the LTPP study is an endeavor known as the Seasonal Monitoring Program (SMP). The SMP primary objective is *“to provide data needed to attain a fundamental understanding of the magnitude and impact of temporal variations in pavement response and material properties due to the separate and combined effects of temperature, moisture and frost/thaw variations”* [5]. In the SMP, 64 road sections, including AC and PCC pavements, distributed over the US and part of Canada were monitored. Different instrumentation was used for different purposes: time domain reflectometry (TDR) was installed to measure moisture content of unbound and subgrade materials, electrical resistivity probes to measure frost locations, and piezometers to measure the depth to groundwater table, among others.

In addition, surface elevation and longitudinal profile data were obtained. The data found in United States and Canada ranged from 1993 to 2004 for both AC and PCC pavements. Rod and level surveys (usually one survey in the middle of each season, especially for non-frost areas)

were conducted to determine changes in pavement surface elevations for five years, on average, at five different locations for AC pavements: 1) pavement edge (PE), 2) outer-wheel path (OWP), 3) mid-lane (ML), 4) inner-wheel path (IWP), and 5) inner-lane edge (ILE), as show in in Figure 1. for PCC pavements, measurements were taken at three different locations: 1) pavement edge (PE), 2) mid lane (ML), and 3) inner-lane edge (ILE), as shown in Figure 2 for JPCP pavements. At the pavement edge, the measurements were taken less than 6 inches from the inside edge of the painted shoulder stripe [5].



**Note:** End of section can be used instead of beginning portion; e.g., test section between stations 3 + 0 and 5 + 00 and instrumentation at appropriate station 5 + 20.

Figure 1: Elevation and Profile Data Collection Plan -AC Pavements [5]

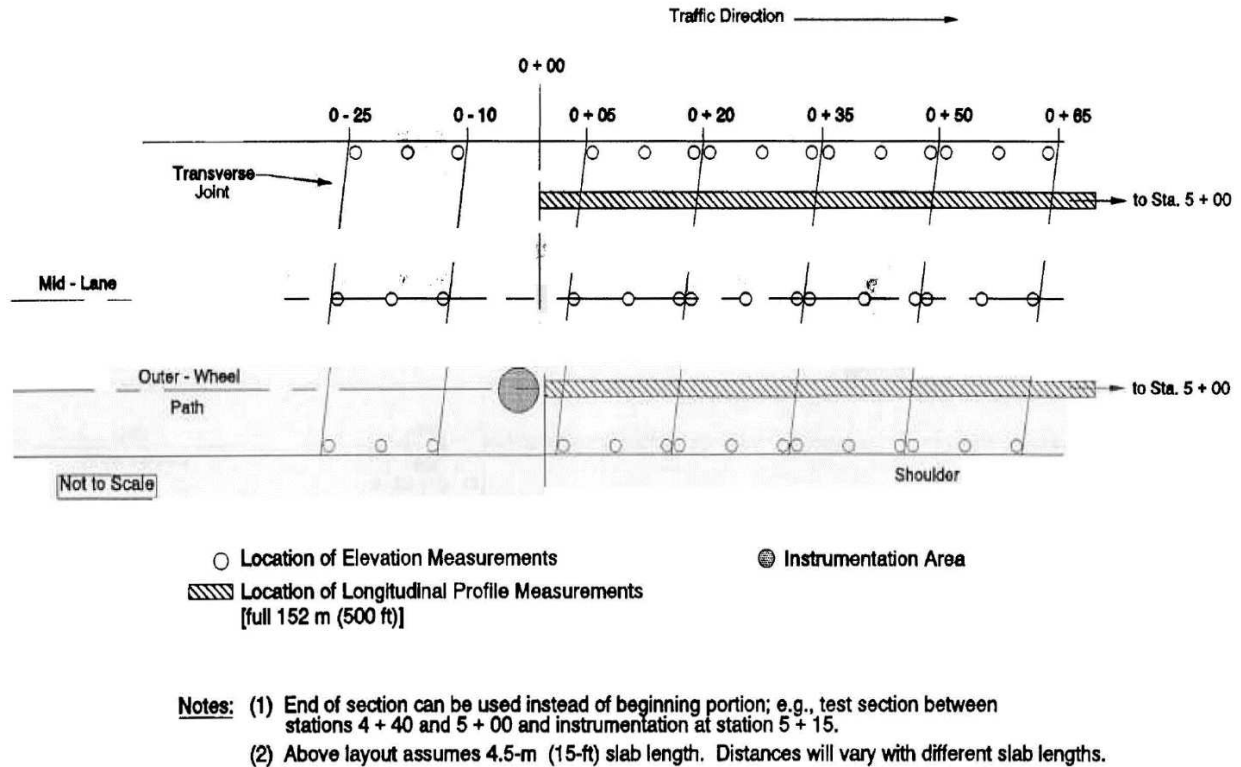


Figure 2: Elevation and Profile Data Collection Plan – JPCP Pavements [5]

## Data Collection

The weighted plasticity index ( $wPI$ ), defined as the product of Plasticity Index,  $PI$ , and percent passing No. 200 sieve,  $P_{200}$ , was calculated and used to define sections with expansive soils potential [6].

$$wPI = \left( \frac{P_{200}}{100} \right) \times PI \quad (1)$$

Soils with  $wPI \geq 10$ , were assumed to be affected by swell/shrink potential. Fifteen out of the 64 sections used in the SMP program were found to have subgrade material with  $wPI$  values close to or greater than 10. Note that although two of the 15 sections, SD 46-0804 and IN 18-3002, have a  $wPI$  value less than 10, they were considered in the analysis because the  $wPI$  of those two sections was calculated as the average value of two tests with one having a  $wPI$  value greater than 10.

The next consideration in the calibration process was the location of the groundwater table (GWT) depth. The free-field (uncovered) shrink-swell model developed by Olaiz et al. (2021), which predicts moisture-driven elevation changes, assumes the depth to stable suction, or equilibrium suction, occurs at a depth above the GWT. This assumption led to the elimination of

five SMP sections from the evaluation process. The 10 sections chosen for the calibration of the volume change due to shrink-swell soils will be referred herein as the “Calibration SMP Sections”. Table 1 presents the Calibration SMP Sections which had stable suction depths above GWT depth (6 AC and 4 PCC pavement sections). In order to consider the rigidity factor, the model calibration was conducted for AC and PCC, separately.

Using the Calibration SMP Sections, changes in elevation over time along the monitored road section were computed from the elevation database. The data collected at the pavement edge was statistically analyzed, and the results were divided based on the pavement type: AC or PCC. The analysis included searching for data that belonged to areas where frost heave and expansive behavior might concurrently occur. When the frost heave susceptibility was moderate or severe, only the elevation change data corresponding to non-freezing months was considered in the analysis.

Table 1: Summary of SMP Sections Soil Properties used in the Calibration Process

<i>Section ID</i>	<i>Pavement Type</i>	<i>% Passing No_200</i>	<i>LL</i>	<i>PI</i>	<i>wPI</i>
AL 01-0101	AC	68	49	14	10
AL 01-0102	AC	61	42	16.6	10
NE 31-0114	AC	95	48	30	28
SD 46-0804	AC	57	33.5	12.5	7
SD 46-9187	AC	64	44	24	21
TX 48-1068	AC	74	38	20	16
KS 20-4054	CRCP/JRCP	92	36	20	23
OH 39-0204	JPCP	74	36	19.7	15
MB 83-3802	JPCP OL w/ AC	92	74	41.5	38
IN 18-3002	JPCP OL w/ AC	67	30.5	14	9

### Data Analysis

As previously mentioned, elevations records were found for five transverse locations: PE, OWP, ML, IWP, ILE. Since the purpose of this study was to calibrate the free-field shrink-swell model with elevation changes data at the pavement edges due to relatively minimal traffic effect, the analysis was calibrated to the pavement edge (PE) data only. Generally, 9 to 17 survey locations about 25 feet (7.5 m) apart were found for each section, as show in Figure 1.

Measured elevation data for the 10 sections were collected and synthesized as follows:

- 1- The data was divided into two groups, depending on the rigidity of the surface pavement. Sections with PCC overlays with AC were categorized as PCC due to the assumption that the rigidity of the PCC governs the volume change reaction in the subgrade.

- 2- For each station location, the initial record was taken as a reference point, and was subtracted from all subsequent elevation readings to compute the relative incremental elevation change since the initial date. This approach provided a relative change in elevation, that would be then compared to the estimated elevation change from Olaiz et al. (2021) model.
- 3- For each elevation measuring date, there were 9 to 17 elevation change values based on the number of the longitudinal stations reported for each road section. The average elevation change, and the standard deviation were calculated to represent volume change data of the entire section, at a particular date.

The procedure followed to calibrate the measured elevation change data with the predicted free-field elevation change model was as follows:

- 1- For each of the Calibration SMP Sections, the monthly elevation change was predicted starting at the construction date.
- 2- The predicted elevation values for the same month/year of the measured elevation records were estimated.
- 3- The predicted values were then normalized to the first value of the measured elevation change, so it would start at the same elevation value. This was done by using the first measured elevation change value as a reference point and subtracting it from the first predicted value, to calculate the “Normalizing Value”. Then, the Normalizing Value was used by subtracting it from all subsequent elevation predictions, as shown in Table 2. Note that the first predicted value, which had been used to calculate the Normalizing Value, was ***not*** included in the developed statistical correlation between the measured and normalized predicted results. Also, it was important to make sure that the reference points were ***not*** value collected when the ground was partially frozen.
- 4- A statistical correlation was developed for the measured and normalized predicted values for AC and PCC separately.

Some records were eliminated due to one, or more, of the following reasons: a) the record contained missing value or incomplete information; b) the record was statistically considered an outlier; and c) evidence that part of the subgrade, which had been defined as susceptible to frost heave, was frozen at the date of the collected record. Table 3 shows the usable data points for each section used in the analysis.

Table 2: Normalizing the Predicted Elevation Values to the Measured Elevation Changes for Section AL 01-0101

<i>Date</i>	<i>Measured (in)</i>	<i>Predicted (in)</i>	<i>Predicted Normalized (in)</i>
11/20/1995	-0.0044	0.0131	-0.0044
01/29/1996	0.0787	0.0081	-0.0094
04/17/1996	0.0612	0.0014	-0.0161
08/22/1996	-0.0175	0.0033	-0.0142
10/10/1996	0.0000	0.0015	-0.0161
10/30/1997	0.0569	0.0005	-0.0170
01/09/1998	0.0306	0.0017	-0.0158
04/25/1998	0.1137	-0.0078	-0.0253
07/20/1998	0.0744	-0.0090	-0.0265
11/11/1998	0.1006	-0.0061	-0.0236
	Normalizing Value	0.0175	

Table 3: Summary of the Data Collected for the Analysis

<i>Section</i>	<i>Pavement Type</i>	<i>No. of Data Points</i>
KS 20-4054	CRCP/JRCP	4
OH 39-0204	JPCP	3
MB 83-3802	JPCP overlay w/ AC	8
IN 18-3002	JPCP overlay w/ AC	2
AL 01-0101	AC	9
AL 01-0102	AC	8
NE 31-0114	AC	2
SD 46-0804	AC	6
SD 46-9187	AC	6
TX 48-1068	AC	10

## Results

This study led to the development of a calibrated mechanistic model that predicts volume change for soils with free access to moisture due to seasonal fluctuations of climate under pavement covered structures. Elevation changes data measured, as part of the LTPP-SMP study, at the pavement edges (PE), was used in the analysis. Initially, 124 data points were collected from 15 road sections, AC and PCC. However, due to the limitation of the free-field shrink-swell volume change model developed by Olaiz et al. (2021), which assumes the depth to equilibrium suction is above the GWT, five road sections and their records were eliminated from the study. In addition, records with frost heave potential were not considered in the analysis.

A total of 58 calibration points were used, 41 from AC pavement sections and 17 from PCC sections. The predicted versus measured elevation change plots are shown in Figure 3 and Figure 4. The equations for AC and PCC are as follows:

$$Y_{AC_{Measured}} = 0.4409 x_{AC_{Predicted}} - 0.0598 \quad (2)$$

$$Y_{PCC_{Measured}} = 1.3968 x_{PCC_{Predicted}} - 0.052 \quad (3)$$

Where, Y is the measured elevation change, and x is the predicted elevation change

These equations were used to adjust and calibrate the proposed free-field shrink-swell volume change model by Olaiz et al. (2021) under pavement covered areas. Given the limitation of the data collected in the general body of literature, the coefficients of determination obtained (61% and 78% for AC and PCC pavements, respectively) provide a preliminary useful approach to adjust the free-field volume change estimates to pavement-edge cover areas until more data becomes available.

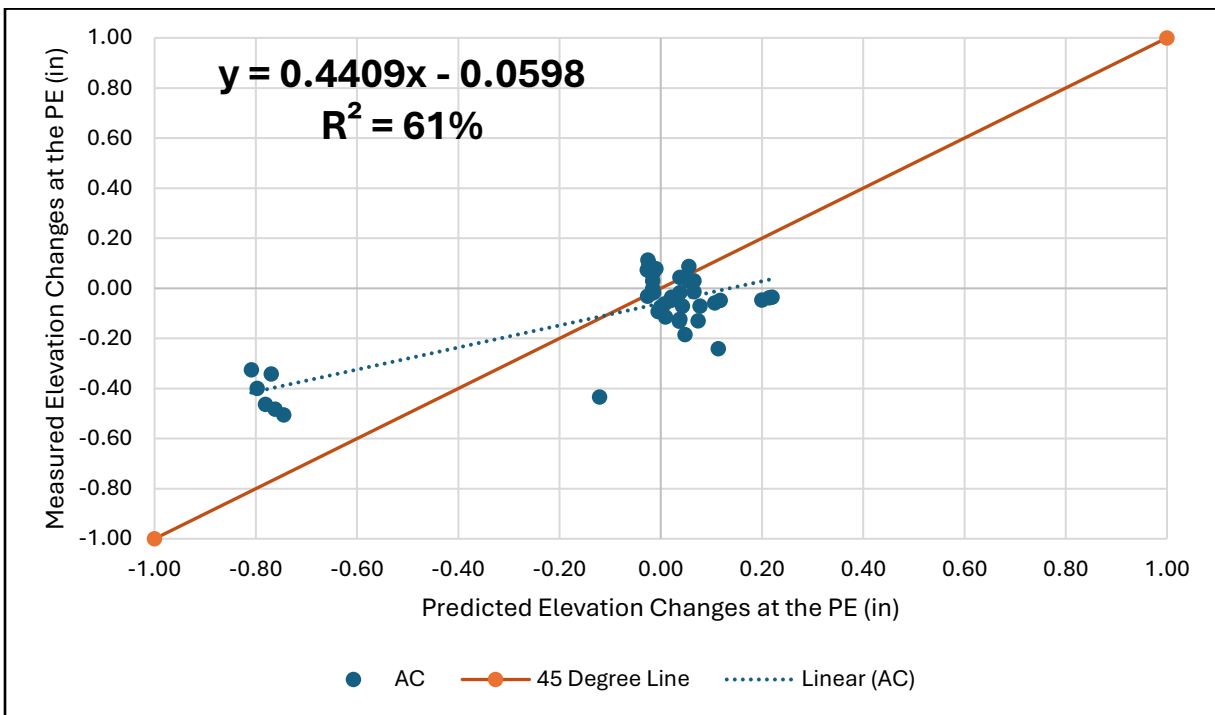


Figure 3: Comparison of Predicted and Measured Elevation Changes for AC Pavements

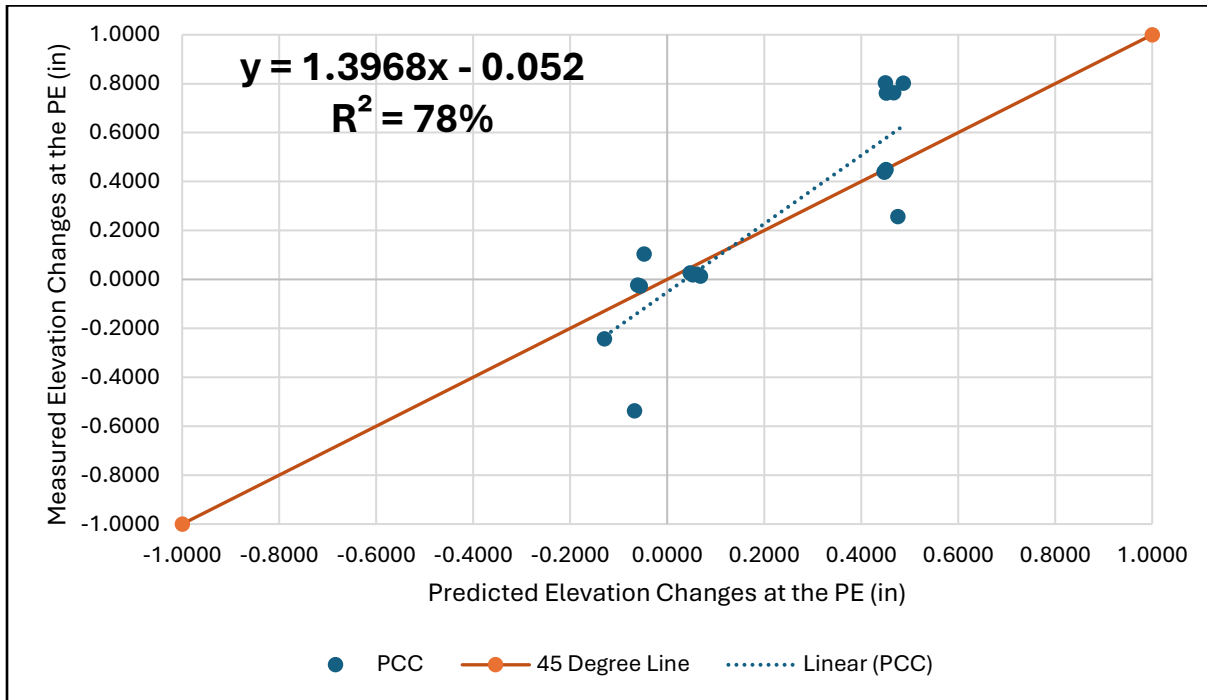


Figure 4: Comparison of Predicted and Measured Elevation Changes for PCC Pavements

### Conclusion

The results presented in this paper constitute a significant step in the overall effort leading to the development of a mechanistic model to predict heave under pavement covered areas. This model provides a more accurate prediction of volume changes due to the existence of shrink-swell soils, which is crucial for pavement design and maintenance. By incorporating the calibrated model into pavement design practices, pavement distress caused by climatic and subgrade conditions can be better estimated. Overall, this research contributes to the advancement of pavement engineering by offering an effective tool for predicting and managing pavement distress caused by volume changes due to shrink-swell soils.

### Data Availability Statement

The raw data is currently available from the first author by request.

### Acknowledgement

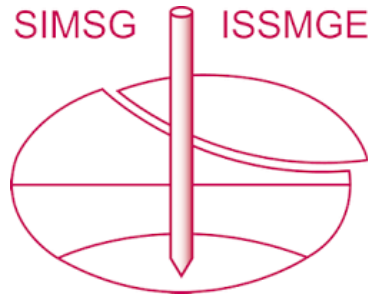
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