**JACKSON SOUTH SNOW SUPPORTING STRUCTURES**
**PROPOSED PERFORMANCE AND HEALTH MONITORING OF**
**WYDOT PROJECT No. N104085,**
**TETON COUNTY, JACKSON, WYOMING**

InterAlpine, Associates, LLC
83 El Camino Tesoros
Sedona, AZ 86336
phone: 928.202.8156

June 29, 2012

InterAlpine Associates, LLC
83 El Camino Tesoros
Sedona, AZ 86336
ph: 928.202.8156

**TABLE OF CONTENTS**



## PROBLEM STATEMENT

This project will provide valuable information on the active snow pressures and in-situ performance of the snow supporting structures (SSSs) at the Milepost 151 site near Jackson, Wyoming. Vibrating wire strain gauges, sensor and snow temperature meters, and snow depth sensors will be installed on two SSSs in summer 2013. The instrumentation will be used to monitor both structural parameters and meteorological conditions over two winter seasons (winters of 2013-2014 and 2014-2015). The internal structure force effects, combined with measured meteorological data, will be used to back analyze the active snow load pressures imparted to the structures. The back-analyzed active snow pressures will be compared to those predicted using existing European methods, which are a function of slope angle, aspect, and ground surface conditions, snow density, structure spacing, and structure geometry. During each summer of the project (i.e., summers 2013, 2014 and 2015), the SSS will be visually observed to document the visual structural health. The instrumentation will not be installed during initial construction for two reasons: a) the distribution of snow on the structures will be observed during the winter of 2012-2013 to help in choosing the two most appropriate SSSs to instrument and b) the instrumentation will require time to procure and prepare for installation.

The results developed in this project will be used to evaluate the performance of the Milepost 151 installation, and will also provide an initial basis for development of design guidelines for future constructed defense measures at other locations within the Western United States. Once awarded, InterAlpine Associates, LLC (InterAlpine) will submit additional proposals to other funding agencies (e.g., National Science Foundation's SGIR program) to be able to expand the scope of work. The expanded scope of work would be primarily aimed at instrumenting additional SSSs, such as the middle section of a 3-plex structure. Obtaining an expanded scope of work would provide additional data that InterAlpine could potentially use to establish a domestic guidance document, such as an AASHTO Design Manual for Snow Supporting Structures.

## BACKGROUND

The 151 Avalanche is located above US 89/191 at Milepost 151 in Jackson, Wyoming. US 89/191 is four lanes and carries an estimated 8,000 vehicles per day in the winter months. It is a well-known hazard and avalanches have struck vehicles, resulting in crashes, traffic delays, and attendant avalanche debris clean-up by WYDOT maintenance crews. The 151 Avalanche has, historically, avalanched to the road 1.5 to 2 times a year. There have been no loss-of-life incidents to date.

Snow supporting structures similar to those being deployed at 151 site have an excellent history of deployment in Europe. However, SSSs in Europe are often deployed in very linear, orderly fashion (Figure 1). Besides the visual blight of this practice, the applicability of the best practices for avalanche hazard management design guidelines (e.g., Margreth 2006) when a more organic deployment plan, such as that for the Milepost 151 project is used (Figure 2) remains unknown. Although the methods of Margreth (2006) were used to estimate the active snow pressures for design of the Milepost 151 project as a matter of best practices for avalanche hazard management, this significant difference in deployment technique suggests that verification is appropriate as a matter of due diligence.

InterAlpine Associates, LLC
83 El Camino Tesoros
Sedona, AZ 86336
ph: 928.202.8156

**Figure 1: Photograph of snow supporting structures typical of European deployments.**

InterAlpine Associates, LLC
83 El Camino Tesoros
Sedona, AZ 86336
ph: 928.202.8156

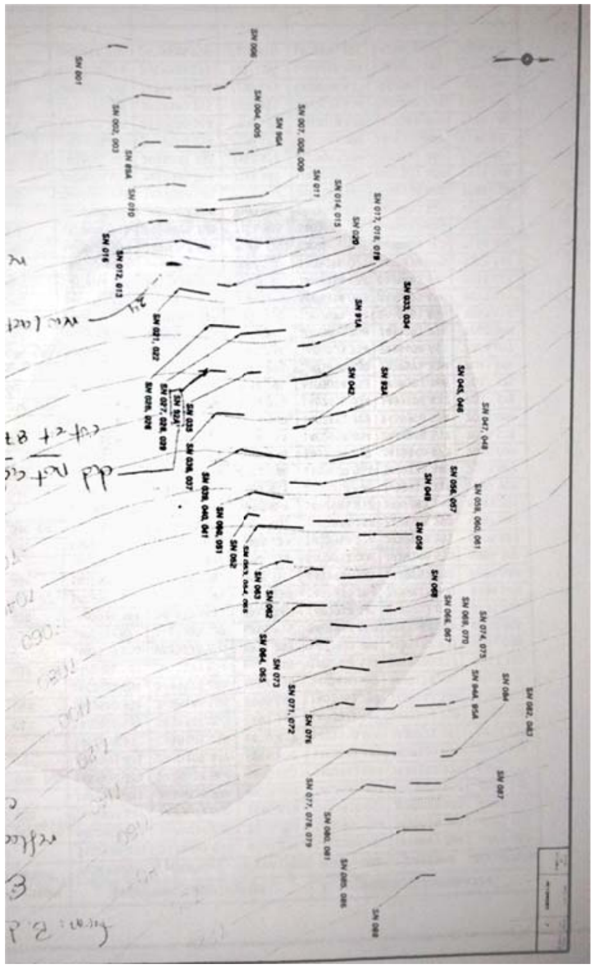

**Figure 2: Planned organic deployment of snow supporting structures at the Milepost 151 site.**

## Snow Loads – Current Understanding

The best available practice is that presented by Margreth (2006) and summarized for use on the Milepost 151 project by InterAlpine Associates (2009). For purposes of brevity, the reader is referred to this latter document.

## Proper Instrumentation

Strain gauges are often used to infer loads within structural steel in laboratory conditions; principals Hewes and Merry have significant experience with these systems. However, exposure of the structural steel to varying thermal conditions leads to thermal expansion or contraction of the structural steel. To infer the internal loads, the thermal strains must be accounted for. This means that the temperature of the structural steel at each point where the strain gauge is installed must be known. Hence, vibrating wire strain gauges, which provide measurements of sensor temperature and strain, will be used rather than resistive strain gauges that are a part of a Wheatstone bridge. Principal Merry used similar vibrating wire transducers during the field testing completed along I-15 in Salt Lake City (Lawton and Merry 2000).

The resonant frequency of vibration of a tensioned steel wire is dependent on the strain or tension in the wire. This fundamental dependency is used to measure a multitude of variables – strain in the case of the proposed project. Vibrating wire sensors are well known for their long-term stability. The advantage of vibrating wire sensors over more conventional types lies mainly in the sensor output, which is a frequency rather than a voltage. Frequencies can be transmitted in electrical cables without appreciable degradation of the signal caused by variations in cable resistance, which can arise from water penetration, temperature fluctuations, contact resistance or leakage to ground. This factor, coupled with the ruggedness of the vibrating wire sensors, results in sensors that exhibit excellent long-term stability and which are ideally suited for long-term measurements in adverse environments.

### Verifying Design Loads through Back-Analysis

As part of the design process, InterAlpine has already developed analytical models for the snow supporting structures. The analytical models were developed in three-dimensions and analyzed using the commercial finite element analysis software SAP2000. The structural elements were modeled using frame elements having six degrees of freedom. The primary loads included in models are dead load and the active snow loads acting on the SSS. We note, however, that the dead load effects are essentially negligible compared to the effects of active snow loads.

The snow pressures acting on the frame elements may be varied until the computed strain response of the analytical model meets the observed strain response provided by the vibrating wire transducers. Having data from the micropile foundations will provide a basis for closure to ensure that the overall forces acting on the structure in the analytical model are in agreement with the observed foundation reactions.

## INVESTIGATIVE METHODOLOGY

The process of load verification and SSS health monitoring will be completed using a three-task scope of work. The following describes the specific scope of work proposed to complete each task.

### Task One: Install Instrumentation System on Snow Supporting Structures

Task One will involve the installation of the instrumentation systems. During the winter 2012-2013, the instrumentation will be procured and prepared for installation in summer 2013. Preparation includes wiring of the instruments to the datalogger and verification of calibration of each strain gauge. Two SSSs will be instrumented, including one stand-alone structure and one end structure as part of a double (side-by-side) pair. The decision of which specific structures to instrument will be made by InterAlpine but submitted to WYDOT for approval.

InterAlpine proposes observing the distribution of snow depth on the newly installed snow supporting structures during the winter of 2012-2013. Based on the observed snow depth across the structures, InterAlpine and WYDOT can make a knowledgable decision on the two structures to be instrumented during the summer of 2013.

For each structure, a total of 16 vibrating wire transducers will be installed: one in each of the four uphill micropiles and twelve on the structural steel. The vibrating wire transducers will be installed as follows:

- For the micropiles, Geokon will install and calibrate vibrating wire transducers within the inner core of short lengths of BX71-51 material (the material that is being used for the micropiles on the Milepost 151 project). The SSS will be temporarily supported so that the uphill rod ends can be removed (one side at a time). The rod ends and adapter couplers will then be removed, the soil and grout excavated back approximately 18 inches, to cut back the micropile with an angle grinder, and the instrumented lengths installed. The rod end adapters and rod ends will be reinstalled and then reconnected to the SSS. Holes will be machined into the rod end adapters to provide access for the electrical cables to the transducers. The process will be repeated at the opposite side.
- For the structural steel, twelve arc-weldable vibrating wire strain gauges will be installed. The two ends of the transducer are welded directly to the CORE10 structural steel. The twelve transducers will be distributed with one along each of the underside of the five crossbeams (at midspan), one each on the underside of the crossbeam at the cantilever side of the girder, and one on each of the rear supporting struts.
- Additional instrumentation will include ultrasonic snow depth gauges and snow temperature gauges. These instruments will be placed on a separate support system held in place similar to the snow sails that have been on site previously.

The data acquisition systems will be powered by a single 12V deep cycle marine battery provided with a solar recharge panel. The dataloggers will include a cell phone modem. This will allow InterAlpine personnel to view the strains and inferred structural loads from remote locations and in real time. Following the completion of this project, the dataloggers and instrumentation would remain on the Milepost 151 site for use in additional research, whether funded by WYDOT or other external funding agencies.

### Task Two: Collect Data for Two Winter Seasons and Visual Evaluations for Three Summers

Following the completion of Task 1, data will be collected for two winter seasons. Data collected will include date and time of each reading, temperature of each transducer, and load or strain, as appropriate. During installation and the following two subsequent summer seasons, InterAlpine personnel will make visual evaluations of the physical condition of all of the installed structures, including a detailed observation of the two instrumented structures. For each of the 87 structure, the visual evaluation will include (at a minimum): observation of the micropiles, micropile to structure connection, general observations of the structural steel, and connections (welds and bolts). These observations will be documented, including with digital photographs. As part of the visual evaluation process, InterAlpine will provide maintenance or repairs to the instrumentation system as needed so that it is ready for the following winter season.

Funds are requested for senior InterAlpine personnel to mobilize to Jackson, WY for each of three summers to complete these activities. However, for summer 2013, this task will be completed concurrently with Task 1; and hence, nonlabor costs for summer 2013 are included in Task 1). Copies of the visual evaluations will be included in the final report (Task Three).

### Task Three: Complete Back-Analysis and Develop Deliverables

The snow pressures in the SAP2000 analytical models will be varied until the computed strain response of the analytical model meets the observed strain response provided by the vibrating wire transducers. The resulting snow pressures will be compared to those in the Swiss Design Guide (Margreth 2006) and significant difference noted. Where possible, the design equations will be modified so that a set of site-specific design recommendations are provided (see Limitations section).

The project, including detailed descriptions of each of the three tasks, will be summarized in a report to WYDOT. If desired by WYDOT, InterAlpine will address one round of comments and provide a final report. The information in this final report will form the basis for white papers to be disseminated at Western Association of State Highway and Transportation Officials (WASHTO) and Transportation Research Board conferences. Should InterAlpine be successful in obtaining additional external funding (e.g., National Science Foundation) for an expanded scope of work, InterAlpine intends that the larger study would lead to domestic design guidance and code (i.e., AASHTO Design Manual) for snow structures for avalanche hazard management of transportation facilities.

## COST ESTIMATE

InterAlpine proposes to complete this three-task project on a lump sum by task, not-to-exceed basis, for $104,566. A summary of the costs are presented in Table 1 and a detailed view by task is presented in Table 2.

InterAlpine Associates, LLC
83 El Camino Tesoros
Sedona, AZ 86336
ph: 928.202.8156

**Table 1: Summary of the lump sum by task, not-to-exceed, fee estimate.**

| INTERALPINE ENGINEERING, LLC - PERFORMANCE MONITORING PROJECT | |
|---|---|
| **Item** | **Cost** |
| Task 1: Direct Labor Costs | $14,805 |
| Task 2: Direct Labor Costs | $30,456 |
| Task 3: Direct Labor Costs | $15,792 |
| Subtotal of Direct Labor Costs | $61,053 |
| | |
| Task 1: Nonlabor Costs | $30,303 |
| Task 2: Nonlabor Costs | $12,810 |
| Task 3: Nonlabor Costs | $400 |
| Subtotal of Nonlabor Costs | $43,513 |
| **Total** | **$104,566** |

InterAlpine Associates, LLC
83 El Camino Tesoros
Sedona, AZ 86336
ph: 928.202.8156

## Table 2: Detailed list of the lump sum by task, not-to-exceed, fee estimate.

| Labor Cost Summary | Rand Decker | Joshua Hewes | Scott Merry | Subtotals/Extensions |
|---|---|---|---|---|
| **Billing Rate:** | $141 | $141 | $141 | |
| **Task 1 - Transducer Installation** | $5,076 | $1,269 | $8,460 | $14,805 |
| Hours | 36 | 9 | 60 | |
| Transducer Procurement and Preparation | 8 | | 24 | $4,512 |
| Micropile transducer installation | 16 | | 16 | $4,512 |
| Arc-Weldable transducer installation | 8 | 8 | 16 | $4,512 |
| Datalogger verification | 4 | 1 | 4 | $1,269 |
| | | | | |
| **Nonlabor Cost Summary:** | Amount | QTY | Ext. | $30,303 |
| Micropile transducers | $318 | 8 | $2,544 | |
| Strain gauge transducers | $156 | 24 | $3,744 | |
| Installation supplies or machining - micropile transducers | $200 | 8 | $1,600 | |
| Installation supplies/welding equipment - strain gauge transducers | $80 | 24 | $1,920 | |
| Transducer wiring | $0.73 | 640 | $467 | |
| VW installation tools from Geokon | $105 | 1 | $105 | |
| Datalogger | $4,500 | 2 | $9,000 | |
| Cell phone modem in datalogger | $900 | 2 | $1,800 | |
| Solar panel | $500 | 1 | $500 | |
| Dry cell Battery | $200 | 1 | $200 | |
| Misc. Supplies (2% of above costs) | $438 | 1 | $438 | |
| Ultrasonic snow depth gauge, temperature transducers | $800 | 1 | $800 | |
| Vibrating wire software by Geokon | $1,500 | 1 | $1,500 | |
| Travel - Arizona or California to Jackson, WY (summer 2013 | $800 | 3 | $2,400 | |
| Per Diem (3 sr. personnel, 5 days each, 1 summer) | $219 | 15 | $3,285 | |
| | | | | |
| **Task 2 - Data Collection and Health Monitoring** | $10,152 | $10,152 | $10,152 | $30,456 |
| Hours | 72 | 72 | 72 | |
| Collect, Reduce, Review Data (4 hrs each sr. personnel per month Dec thru March, 2 winters) | 32 | 32 | 32 | $13,536 |
| Visual Evaluations (40 hrs each of 3 summers) | 40 | 40 | 40 | $16,920 |
| | | | | |
| **Nonlabor Cost Summary:** | Amount | QTY | Ext. | $12,810 |
| Travel - Arizona or California to Jackson, WY (summers 2014 and 2015 | $800 | 6 | $4,800 | |
| Per Diem (3 sr. personnel, 5 days each, 2 summers) | $219 | 30 | $6,570 | |
| Cell phone charges for data collection ($30 per line (2 lines) for 24 months) | $30 | 48 | $1,440 | |
| | | | | |
| **Task 3 - Back Analysis and Develop Deliverables** | $4,794 | $9,024 | $1,974 | $15,792 |
| Hours | 34 | 64 | 14 | |
| Back Analysis and Review | 14 | 40 | 4 | $8,178 |
| Develop Deliverables | 20 | 24 | 10 | $7,614 |
| | | | | |
| **Nonlabor Cost Summary:** | Amount | QTY | Ext. | $400 |
| Reports: Draft and Final | $400 | 1 | $400 | |
| | | | | |

InterAlpine Associates, LLC
83 El Camino Tesoros
Sedona, AZ 86336
ph: 928.202.8156

## AUTHORIZATION

InterAlpine proposes that our services be performed in accordance with the Master Service Agreement (MSA) signed June 2010.

## LIMITATIONS

As part of this project, data will be limited to that obtained from two structures. If possible, the design equations provided in the Swiss Guide will be modified to provide a set of site-specific recommendations. As such, these recommendations are not sufficiently validated to establish design codes suitable for all areas and design conditions. Users should exercise engineering judgment and employ the same caution as when using the Swiss Design Guide.

InterAlpine will perform its services in a manner consistent with the standards of care and skill ordinarily exercised by members of the profession, practicing under similar conditions and locations at the time the services will be performed. Acceptance of this proposal neither makes nor intends a warranty or guarantee, express or implied, nor does it create a fiduciary responsibility to WYDOT by InterAlpine.

## REFERENCES

InterAlpine Associates (2009). Snow Supporting Structures for Avalanche Hazard Reduction, 151 Avalanche, Highway US 89/191, Jackson, Wyoming, Final Report FHWA-WY-09/05F, 130 pages, April.

Lawton, E.C., and Merry, S.M. (2000). "Performance of Geopier Reinforced Soil Foundations During Simulated Seismic Tests on I-15 Bridge Bents," Transportation Research Record No. 1736: Soil Mechanics 2000, Transportation Research Board, Washington, D.C. pp. 3-11.

Margreth, S. (2006). "Technical Guideline for Defense Structures in Avalanche Starting Zones." Environment in Practice No. … Federal Office for the Enviornment, Bern; WSL Swiss Federal Institute for Snow and Avalanche Research, Davos, 134 pp.