The following relevant material for the C21 webpages has been collected by Engineering Geology students of Prof. Scott Burns at Portland State University (USA) in the framework of a students assignment. This material has not yet been screened and commented nor approved by the C21 chair and membership.

Relevant Journal Articles

Ferrians, O.J., Jr., Kachadoorian, Reuben, and Greene, G.W., 1969, **Permafrost and related engineering problems in Alaska**: U.S. Geological Survey Professional Paper 678, 37 p. http://www.dggs.dnr.state.ak.us/pubs/pubs?reqtype=citation&ID=3938

Permafrost, or perennially frozen ground, is a wide-spread natural phenomenon. It underlies approximately 20 percent of the land area of the world. The permafrost region of Alaska, which includes 85 percent of the State, is characterized by a variety of permafrost-related geomorphic feature including pattered ground, pingos, thaw lakes, beaded drainage, thaw or thermokarst pits, and muck deposits. Known perma-frost thickness ranges from about 1,300 feet near Barrow in northern Alaska to less than a foot at the southern margin of the permafrost region. The distribution of permafrost is controlled by climactic, geologic, hydrologic, topographic, and botanic factors.
The extensive permafrost region of Alaska poses special engineering problems for the design, construction, and maintenance of all types of structures. Lack of knowledge about permafrost has resulted in tremendous maintenance costs and even in relocation or abandonment of highways, railroads, and other structures. Because of the unique geologic-environmental conditions that exist in permafrost areas, special engineering procedures should be used, not only to minimize disruption of the natural environment, but also to provide the most economical and sound methods for developing the natural resources of the permafrost region of Alaska.

Goering, D.J., 2003, **Passively Cooled Railway Embankments for Use in Permafrost Areas**: Journal of Cold Regions Engineering. 17:3, p. 119-133. Permalink: http://dx.doi.org/10.1061/(ASCE)0887-381X(2003)17:3(119)

An experimental air convection embankment (ACE) was constructed in Beiluhe on the Qinghai-Tibet Plateau during 2001–2003, using coarse (5–8 and 40–50 cm), poorly graded crushed rock fill material on the slope of embankment with thick ground ice permafrost foundation, which should be called the air convection embankment with crushed rock slope protection (ACE–CRSP). The highly permeable ACE–CRSP installation was designed to test the cooling effectiveness of ACE–CRSP concept in an actual railway project. Ground temperature data were collected from test sections on the railway with thermistor sensor strings. The results showed that the mean ground temperature under the layer of the crushed rock with coarse particle diameter of 40–50 cm was lower than that under one with finer particle diameter of 5–8 cm, and the fluctuating range of temperature under the former was bigger than that under the latter. It was obvious that the maximum thaw depth was raised under the layer of crushed rock with coarse particle diameter of 40–50 cm, which resulted from the stronger cooling effectiveness of air convection during the winter. The amount of heat exchange also showed that the absorbed cooling energy of the foundation, under the layer of the crushed rock with coarse diameter, was larger than that with finer diameter.So, we

believe that the cooling effectiveness of the crushed rock layer with coarse diameter was stronger than that one with finer diameter.

Guodong, C., 2003. **Research on engineering geology of the roadbed in permafrost regions of Quinghaixizang Plateau**. Quaternary Science. 2. DOI : cnki:ISSN:1001-7410.0.2003-02-002

In the permafrost regions of the Qinghai Xizang Plateau, many important engineering constructions,such as the gas pipeline from Golmud to Lhasa, fiber cable from Lanzhou to Xining and to Lhasa, Qinghai Xizang (Qing Zang) Highway (HWY 109), Xining Kangding (Qing Kang) Highway (HWY 214) and Xining Zhangye (Ning Zhang) Highway (HWY 227), have been completed. To summarize the engineering geological works of these constructions is of significance for guidance to the on going construction of Qinghai Xizang Railway, and to the future projects such as the construction of electric cable system and the diversion of river water from south to north in the western China. 1 Engineering geologic survey of permafrost The distribution of permafrost, especially the underground ice, is usually discontinuous in space. This phenomenon creates difficulties for geological investigation. Application of ground penetrating radar has greatly eased such difficulties and increased the accuracy of detection. A series of detailed regulations for engineering geological survey in permafrost regions of the Qinghai Xizang Plateau have been worked out based on practical investigations and theoretical researches over the past several decades. These regulations have been applied for guidance to the engineering geological works for Qinghai Xizang Railway construction in the permafrost region. Ground temperature and ice content are two main factors controlling the roadbed stability. They are also the unique indices for the engineering geological survey in permafrost regions. Many researches on these two factors have been conducted in the past several years. It has been found that 76% of the permafrost along the Qing Zang Highway is high temperature permafrost, and 59% belongs to high ice content permafrost. The thermo stability of roadbed in permafrost regions has been classified and evaluated based on the ground temperature and ice content. 2 Forecast of permafrost engineering and geological perspectives To forecast the changes of permafrost under natural conditions and mankind activities is important to guarantee the accuracy of engineering design. About 12 monitoring stations have been established and ground temperatures in more than 150 boreholes have been monitored along Qing Zang Highway since 1973. The longest record for continuous observation reaches 12 years. Six sections and 65 boreholes are currently still under regular monitoring along the highway. For the Qing Kang Highway, monitoring on experimental embankment has been conducted in Huashixia of Qinghai Province since 1996, and has covered an accumulated distance of about 2 200 km, including 9 sections over 4 different permafrost types. Based on the analysis of the large amount of data, the following conclusions can be drawn and are of importance to research on roadbed engineering geology in permafrost regions. (1) There is an obvious trend of permafrost degradation. The north limit of permafrost has retreated about 0.5～1 km southwards, and the south limit has retreated about 1～2km northwards under natural condition. Combined with the effects of road, the predominantly continuous permafrost has decreased about 28 km from 550 km in 1979 to 522 km in 1991, while the island permafrost decreased about 19 km from 210 to 191 km. The main damages to the road along the highway are caused by thawed settlement and frost heave. Taken the Qing Zang Highway as an example, about 85% of the roadbed damages can be attributed to thawed settlement, and the other 15% are resulted from frost heave and frost boiling. (2) The stability of roadbed in permafrost region is closely related with ground temperature. After the pavement of asphalt on the Qing Zang Highway,

60% of the road underlain by permafrost forms the thawed inter layer and most of such sections belong to high temperature permafrost. The monitoring data indicate that measures by increasing heat resistance (such as increasing the height of roadbed and application of heat insulation materials) play a role in low tem

Lai, Y., Wang, Q., Niu, F., and Zhang, K. 2004. **Three-dimensional nonlinear analysis for temperature characteristic of ventilated embankment in permafrost regions**. Cold Regions Scenice and Technology. 38:2-3, p. 165-184. DOI: doi:10.1016/j.coldregions.2003.10.006

A ventilated embankment with pipes inside is proposed for application in the field. The pipe's diameter is 0.4 m; its position is 1.0 m above the natural surface; and the distance between its centers is 2.0 m. Using the finite element method, the three-dimensional numerical analysis for the temperature characteristic of the ventilated embankment has been performed. The calculated result indicates that the ventilated embankment enables the area of thawing bulbs under it to decrease, the largest thawing depth to shrink, and the isotherm of 0 °C to move up into regions at which the yearly average air temperature is −2.9 °C, or the yearly average temperature on the natural surface is −0.4 °C without climatic warming. This illustrates that the ventilated embankment is able to play a cooling role to the permafrost under it and is able to reduce the embankment base temperature, which ensures the stability of embankment in permafrost regions. Considering the case where the air temperature will increase by 2 °C in 50 years, the ventilated embankment structure used for 50 years can also ensure the thermal stability of permafrost under it in the regions where the yearly average air temperature is below −3.5 °C, or the yearly average temperature on natural ground surface is below −1 °C.

Lai, Y., Zhang, S., Zhang, L. and Xiao, J., 2004, **Adjusting temperature distribution under the south and north slopes of embankment in permafrost regions by the ripped-rock revetment**. Cold Regions Science and Technology, 39:1, p. 67-79. DOI: doi:10.1016/j.coldregions.2004.04.003

In this paper, the finite-element formula of convective heat transfer in porous media is obtained by using the Galerkin's method according to the continuity, momentum and energy equations of fluid heat convection for solving the computational problem of temperature field on the ripped-rock revetment embankment in Qing–Tibetan railway. The temperature changes of the ripped-rock revetment and common ballast embankments with south and north slopes have been investigated in coming 24 years, respectively. The results indicate that the ripped-rock of 10 cm diameter is paved on the south and north side slopes of common embankment ballast with the corresponding thickness of 1.6 and 0.8 m, respectively, when the temperature difference of the south and north slopes is 1.8 °C, which is able to make the temperature field distribution symmetrical during summertime, permafrost table greatly raised above the native ground surface with frost-susceptible sub-clay (the active layer before embankment construction) completely frozen under embankment during the time, and eliminate the disasters of longitudinal cracks resulting from the uneven settlement of embankment. Thus, we strongly suggest that the ripped-rock revetment embankment be adopted as a kind of embankment structure of Qing–Tibetan railway with south and north slopes in permafrost regions in order to protect the railway as much as possible.

Li, N., Cheng, G., Zu, Z, and Zhu, Y. 2001. **The advance and review on frozen soil mechanics. Advances in Mechanics.** 1. DOI : cnki:ISSN:1000-0992.0.2001-01-008.

The recent advances in frozen soil mechanics are demonstrated and discussed from four aspects: (1) Test studies on the mechanical properties of the frozen soil; (2) Heat conductivity properties of the mixture materials of the freezing soil; (3) Water migration behaviors in the freezing soil; and (4) The Heat-Moisture-Deformation Coupling Models. A discussion on above four areas is made for further researches, and suggestions are offered as follows: (a) The research should be transferred from the deformation and strength properties of the frozen soil to the heat and moisture migration behaviors of the freezing and thawing soil, which is often important in engineering. (b) More attentions should be paid to the field tests with complex water and heat boundaries, instead of the lab tests with very simple boundaries. (c) The structure and grade size distribution of the frozen soil should be considered in the further test studies.

Li, S. and Wu, Z., 1997. **The change of thaw bulb under asphalt pavement in the region of permafrost on the Tibetan Plateau**. Journal of Glaciology and Geocryology. 2. DOI : cnki:ISSN:1000-0240.0.1997-02-003.

After a highway is built with dark asphalt pavement in the region of permafrost on the Tibetan Plateau, the relationship of heat exchange between atmospher and highway surface is changed. Especially, water evaporation from highway surface greatly decreases, thus the temperature of highway surface suddenly icreseases. Then the permafrost temperature increases and the permafrost table under roadbed drops year by year. As a result, veritically unlinked condition of permafrost appears and a residual thawed layer occurs between the bottom of seasonal freezing layer and the top of permafrost (named thawing bulb). The residual thawed layer is gradually developing year by year, ground ice in permafrost layer is thawing, a settlement of roadbed appears, and the communication and transportation will suffer from the thaw bulb.

Liu, J. and Tian, Y., 2002, **Numerical studies for the thermal regime of a roadbed with insulation on permafrost**. Cold Regions Science and Technology. 35:1, p. 1-13.

2-D finite element analysis applied to the roadbed with insulations (Expandable Polystyrene, EPS; Polyurethane, PU) in different depths on Fenghuoshan permafrost zone of Tibet was conducted. By changing the insulation's dimension and position, a series of computer simulations were carried out. The simulated thermal states of roadbed and the base for the modeled cases for the following 50 years are presented and discussed, the main influencing factors were outlined.

Zhang, L., 2000. **Regularity of ground temperature variation in Qinghai-Tibet Plateau permafrost region and its effect on subgrade stability**. China Railway Science. 1. DOI : cnki:ISSN:11-2198.0.2000-01-005

Based on the analytical study of ground temperature data and relevant numerical simulation analysis of typical sections along Qinghai Tibet Railway in the past 30 years,the paper holds that the phenomenon of global temperature rising causes the ground temperature field in the local permafrost region to change in the direction unfavorable to permafrost existence.As a result obvious variation of plateau permafrost engineering geology environmental conditions and characteristics is observed.The variation will produce great effect on the construction of railway subgrade and the stability of the subgrade during traffic operation. It is of realistic and previsingsignificance to study,analyse and predict the mode of variation of the ground temperature and foretell the development tendency of the plateau permafrost to the benefit of design, construction and operation of Qinghai Tibet Railway.

Zhi, W., Yu, S., Wei, M., and Jilin, Q., 2005, **Evaluation of EPS application to embankment of Qinghai-Tibetan railway**. Cold Regions Science and Technology. 41:3, p. 235-247. doi:10.1016/j.coldregions.2004.11.001

In many cases, protecting permafrost from further thaw due to human activities might be the first choice for embankment design in permafrost regions. The observation data of an embankment with insulation at the Beiluhe site are analyzed. Two-dimensional finite element analyses are conducted, in which phase change is taken into consideration to simulate the thermal regime of the Qinghai–Tibetan railway with expanded polystyrene (EPS). Based on the predicted maximum thaw depth in the following 50 years, the best position for insulation is presented and the relationship between the thickness of insulation and the height of embankment is analyzed. Also, the applicable range of insulation in embankment engineering of the Qinghai–Tibetan railway in terms of mean annual air temperature (MAAT) is suggested and the influence of the geothermal field of permafrost on the applicable range of the insulation is discussed.

Zhizhong, S., Wei, M., and Dongquing, Li., 2005, **In situ test on cooling effectiveness of air convection embankment with crushed rock slope protection in permafrost regions**. Journal of Cold Regions Engineering. 19:2, p. 38-51. **Permalink:** http://dx.doi.org/10.1061/(ASCE)0887-381X(2005)19:2(38)

An experimental air convection embankment (ACE) was constructed in Beiluhe on the Qinghai-Tibet Plateau during 2001–2003, using coarse (5–8 and 40–50 cm), poorly graded crushed rock fill material on the slope of embankment with thick ground ice permafrost foundation, which should be called the air convection embankment with crushed rock slope protection (ACE–CRSP). The highly permeable ACE–CRSP installation was designed to test the cooling effectiveness of ACE–CRSP concept in an actual railway project. Ground temperature data were collected from test sections on the railway with thermistor sensor strings. The results showed that the mean ground temperature under the layer of the crushed rock with coarse particle diameter of 40–50 cm was lower than that under one with finer particle diameter of 5–8 cm, and the fluctuating range of temperature under the former was bigger than that under the latter. It was obvious that the maximum thaw depth was raised under the layer of crushed rock with coarse particle diameter of 40–50 cm, which resulted from the stronger cooling effectiveness of air convection during the winter. The amount of heat exchange also showed that the absorbed cooling energy of the foundation, under the layer of the crushed rock with coarse diameter, was larger than that with finer diameter.So, we

believe that the cooling effectiveness of the crushed rock layer with coarse diameter was stronger than that one with finer diameter.

Wu, Q., Shi, B. and Liu., Y., 2003, **Interaction study of permafrost and highway along Quinghai-Zizang Highway**. Scence in China Series D: Earth Sciences. 46:2, p. 97-105. DOI: 10.1360/03yd9009.

Eight monitoring sites are set along the Qinghai-Xizang Highway (QXH) to investigate the characteristics and process of interaction between permafrost and highway, including the upper and down boundaries of active layer under natural surface, seasonally freezing-thawing depth under asphalt pavement, permafrost table temperature and roadbed stability. The investigation results show that the changes of active layer thickness and permafrost table temperature under asphalt pavement are greater than these under natural surface due to the absorbing heat action and less evaporation of asphalt pavement, as a result, the engineering geological problems such as thaw settlement and frost heave present frequently along QXH line and produce the adverse impact on roadbed stability.

Zhang, J., Wu, J., and Li, Z., 1999. **The study of highway construction techniques on plateau permafrost regions: Review and prospect**. Journal of Glaciology and Geocryology. 2. DOI: cnki:ISSN:1000-0240.0.1999-02-020.

Qinghai-Tibet Highway is the key way to join the Tibetan Autonomous Region and Qinghai Province, and is the best useful entrance and exit of the Tibetan Autonomous Region whih provides more than 85 percent of goods from the other inner provinces to the region. This paper reviews every steps of the 40 years studying in several topics, and sums up the content and the fruits. The methods of exploring technique is developing from drilling to a combination of drilling and radar. The subgrade is developing to use the methods of elevating the height of fill, setting heat insulation and setting waterproof and heat preservation side-road. The pavement is developing to use modified asphalt concrete and steel fiber concrete now, from grit and aggregate pavement in the 1950's to asp. macadam pavement, bituminous surface treatment pavement in the 1970's. The bridge and culvert is developing from wooden structure mainly in the 1950's and 1960's to reinforced concrete and prestressed reinforced concrete. At the same time the permafrost and the temperature field along the way is studied. Further research on the Qinghai-Tibet Highway is suggested in order to be a sustainable development way and to mitigate the diseases on subgrade, pavement and bridge.