

降低黄土液化势的改性技术分析^①

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摘要:提出针对低黏性粉土等易液化土样采用酸化学改性方法。改性后的低黏性土液化试验曲线表明,在50~80 kPa 动应力下孔隙水压力上升很小,应力降低很小。该方法能达到有效降低液化势,提高土体强度的目的。

关键词:黄土; 黄土液化; 改性技术

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Analysis of Modification Technique for Reducing Loess Liquefaction Potential

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Abstract: Loess in China are mainly distributed in the terraces of the Yellow River, including in the Gansu, Ningxia, Inner Mongolia, and Shanxi provinces, covering an area of 6.4×10^6 km² that accounts for about 6.6% of China's territory. The loess in western Gansu belongs to the class of unsaturated loess with a wide distribution range. Formed near the sand source, the eolian loess mainly includes sand loess, low-viscosity loess, and clay loess.

Low-viscosity loess in Gansu has large thickness, with development pores and aerial weak cementation, which under dynamic loading is likely to produce large settlement deformation. It also has strong water-collapse characteristics and a tendency toward liquefaction. Such material brings arduous engineering challenges and foundation treatment construction problems. Low-viscosity loess in general has weak alkaline and poor cementation strength, with large deformation under a force dynamic. Because underground water easily uplifts after loading, liquefaction is a serious problem. Acid-modified and chemically modified technology can effectively improve the loess seismic subsidence problem.

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The principle of acid-modified loess chemical modification is using phosphoric acid and a weak acid as a loess acidification treatment, considering that the loess formed in a dry climate gives priority to calcium carbonate. Then, other salts (Boric salt) are added to form the cementation bonds such as boron bridge bonding and hydrogen bonding. Filling material (calcium salt) is added to adjust the ratio of particle size to reduce the liquefaction potential. The acid-modified method reduces the low-cohesion loess' ability to liquefy. The liquefaction test showed that under 50~65 kPa dynamic stress, the modified loess had a very slow rise in pore water pressure, a very small deformation, and almost no stress reduction. Under a dynamic stress of 65 kPa, its liquefied deformation was no more than 0.2%, corresponding to resistance to an IX-level earthquake. The following ratio was confirmed: 10%~30% calcium, 6%~13% boron material with 3% phosphoric acid. If a higher level of anti-seismic resistance is required, add 8%~13% of boron material.

The acid-modified method creates no chemical toxicity, and the price of the raw boron material is lower than that of the lime cement. Therefore, this method has some economic and social benefits.

Key words: loess; loess liquefaction; modification technique for loess

0 引言

我国黄土主要分布于黄河中下游的甘肃、宁夏、内蒙古、陕西、山西,河南和河北诸省,在新疆也有非饱和黄土分布,覆盖面积达 $6.4 \times 10^6 \text{ km}^2$, 约占我国领土面积的 6.6%。特别是甘肃省陇西地区黄土分布范围广,厚度大。由于形成靠近沙源,多属于风成黄土,主要包括砂黄土、低黏性黄土和黏黄土。

低黏性粉质黄土具有厚度大,孔隙极为发育的特点,其特殊的架空弱胶结微观结构导致动荷载作用下强度低、震陷变形大、湿陷性强、更容易液化等特性,为工程建设提出了艰巨的地基处理难题^[1]。已有的传统黄土改性方法相关文献曾提出石灰改性黄土提高强度的最佳石灰掺合比^[2];粉煤灰对填埋场黄土垫层改性^[3];利用动三轴试验研究改性黄土的动力特性,确定粉煤灰改性黄土最佳粉煤灰含量在 15%~20%^[4]。笔者通过微观检测和酸化学改性方法提出的非饱和黄土改性技术能有效改善非饱和黄土的抗震陷性和湿陷性^[5-6]。此外,我国黄土微观结构类型与分布区域有关^[7],需要按照微观结构类型确定合理经济的土层改性方案。本文在此技术的基础上,对比低黏性粉土改性后土样的液化特性做进一步的测试检验分析。

1 酸改性方法简介

低黏性粉土多呈弱碱性,胶结力差,在动荷载作用下的震动变形系数较大,震动后容易导致地下水位上移,产生液化,严重时导致地基下沉,建筑物倾

斜,或场地现场无法正常施工。酸改性化学改良的技术可能有效改善这种粉土的液化问题。酸改性黄土的化学改良技术原理是利用磷酸等弱酸对土进行酸化处理^[6],破坏其干燥气候下形成的以碳酸钙弱胶结为主的粒状架空微结构;然后加入其他盐类,重新形成起胶结作用的化学键,如形成硼桥键,磷氧键,氢键等;同时加入填充料,调整颗粒粒径配比,从而达到降低土的残余变形系数,降低液化势的改性目的。

采用永登低黏性粉土,参考文献[6]的 h4 号配方,调整配比,添加增强材料,考察低黏性粉土改性后液化势的变化。配制土样的含水量 18.7%,干密度为 1.6 g/cm^3 。

2 液化试验测试

选择酸改性配方制样后,利用 WF-12440 型动三轴扭剪仪进行试验。选用 50 mm(直径)×100 mm(高)的试样,在固结时采用等压固结,固结压力分别采用 100 kPa、150 kPa 和 200 kPa。试验时的动荷载采用频率为 1 Hz 的等幅正弦荷载,采样率(N)为 100/s,振次为 $N/100$ 。

选取动荷载动应力测试酸改性黄土,原状低黏性土样的液化如图 1。试验结果表明土样在 25 kPa 动应力下作用仅 28 振次后即液化,变形达到 6%,对应的孔隙水压力为 60 kPa。

图 2 所示为不同动荷载动应力下测试获取酸改性黄土的液化曲线,动荷载分别为 50 kPa、65 kPa、

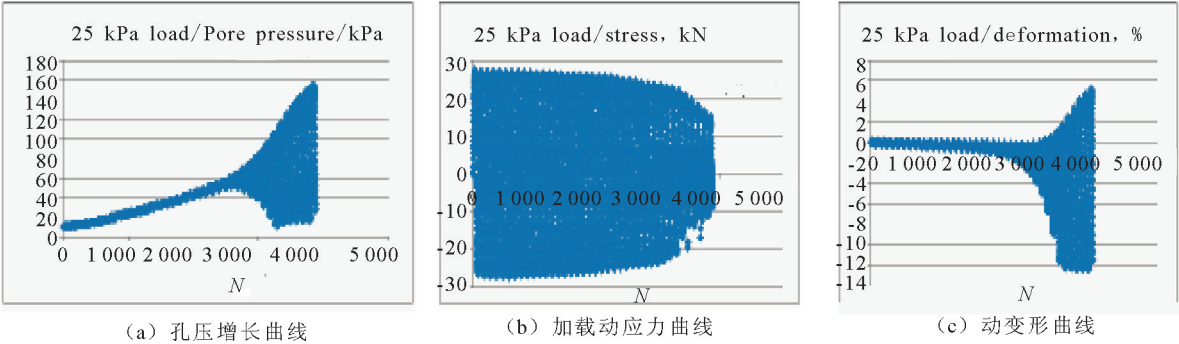


图 1 25 kPa 动应力下的原状粉土(固原 8 m)的液化曲线

Fig.1 Liquefaction curve of the undisturbed loess (Guyuan 8 meter depth) under 25 kPa dynamic stress

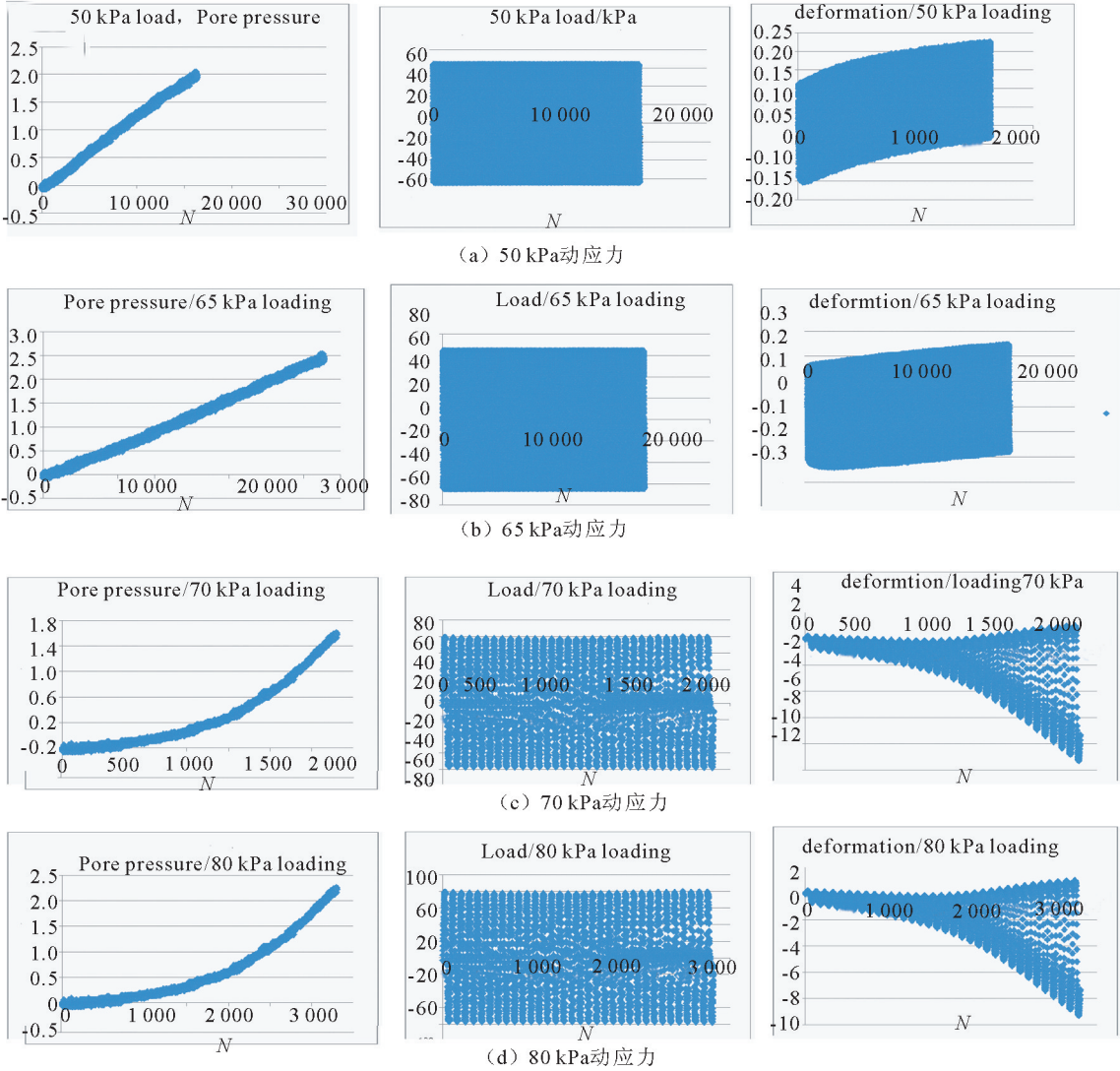


图 2 不同动应力下改性后黄土的液化曲线(分别为孔隙水压力曲线,动应力加载曲线,液化变形曲线)

Fig.2 The liquefaction curves of modified loess under different dynamic stresses

70 kPa 和 80 kPa 动应力下的液化曲线。图 2(a), (b)分别为 50 kPa、65 Pa 动应力下改性后土样(固原 8 m 土样)的液化曲线。其中 50 kPa 和 65 kPa 动应力下的孔隙水压力上升很小,仅为 2 kPa 和 2.5

kPa,加载动应力振次在 150 次以上,动变形不超过 0.2%和 0.25%。在 80 kPa 动应力下(图 2(d)),改性土最大孔隙水压力为 2.5 kPa,而在 25 kPa 动应力同样振次下,原状黄土最高孔隙水压力为 180 kPa。此外,应力曲线几乎没有下降,如图 2(d),即使在 80 kPa 动应力作用下,振动 300 次以上,土体应力也没有下降。改性土的液化动变形曲线差异较大,在 50 kPa 和 65 kPa 动应力下,动变形不超过 0.25%和 3%(如图 2(a),(b));在 70 kPa 和 80 kPa 动应力下(图 2(c),(d)),最大动变形不超过 10%。根据液化的最大动应力为 65 kPa 代入估算式(1)^[1],计算出最大加速度为 641 gal,即地震烈度超过Ⅸ度。即在 65 kPa 的动应力下,地震烈度超过Ⅸ度时,液化变形不超过 0.2%,孔隙水压力仅为 2.5 kPa。

$$\tau_d = 0.65 \gamma_d h_i \frac{\alpha_{\max}}{g} K_d \tag{1}$$

式(1)中 τ_d 为动剪切应力; K_d 为动力折减系数; h_i 为分层厚度; γ_d 为黄土密度(kN/m^3);动应力 $\sigma_d = 2\tau_d$)

3 结论及应用

(1) 酸改性低黏性土液化试验表明,在 50~80 kPa动应力下,改性土的孔隙水压力上升很小,变形很小,应力几乎没有降低;65 kPa 动应力下液化变形不超过 0.2%。该方法达到Ⅸ度烈度下不液化的水平。酸改性后的土样经震陷试验表明震陷系数最低降到 0.7%以下,其防震陷变形和液化效果均较为显著。

(2) 施工中湿陷性黄土一般采用换土回填法。施工时挖出需要处理的原状土,加入配方配比的填料和稀释后的磷酸水溶液,搅拌混合均匀后回填即可达到处理效果。由于黄土的微观结构与区域成土年代有关,在实际的操作中,还要针对不同场地和不同深度的土层进行配方调整。所加入的填料本身没有化学毒性,酸改性方法主要原料的硼料价格与水泥相当。总成本与石灰水泥改良土的价格相当。其

他的填料和助剂价格成本低廉,因此该方法具有较好的经济和社会效益。

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