美国犹他州盐湖城I-15工程 The I-15 in Salt Lake City, Utah US

美国亚利桑那州大面积地表是由粘质土壤构成的。当在这样的粘土上修建桥梁时，粘土收缩，根基就塌陷了。这种“固结沉降”现象在公路建设中司空见惯。发生这种现象时，桥面就变得高低不平：汽车音响的CD振动是其中最小的问题了。它还可以导致降低交通速度，也可能损坏像自来水干线、污水管道和供电电缆这样的地下公共设施。修复固结沉降导致的破坏需要花费时间和金钱。有时，施工人员为了使表面平整，在表层安装加强肋，在极度恶化的情况下，还得进行重新修建引桥。

A lot of the ground in the US state of Arizona is made of saturated clay. When a bridge is built on top of this the clay compresses and the foundations sink. This "consolidation settlement" is common in road construction. When this happens the surface of the bridge can become uneven: CDs jumping in car stereos is the least of their problems. It can lead to the need to reduce traffic speeds. Underground utilities such as water mains; sewer lines and electricity cables can also

桥梁交叉口上典型的地基泡沫装置
Typical geofoam installation at a bridge crossing

轻型解决方案

美国工程师使用地基泡沫在粘质土壤上修建桥梁

撰文：史蒂文·巴特利特

Lightweight solution

US engineers use geofoam to build bridges on saturated clayey soil

By Steven Bartlett

10米高的挡土墙或堤坝修建在饱和地基土上时，一般会发生1米左右的固结沉降。这些土壤需要两年时间才能完全固结沉降。工程师有足够的时间修建更高的堤坝，使它高出桥梁40%。一旦发生沉降，工程师可以移动高出的堤坝。

要不是犹他州盐湖城州际项目I-15，美国工程师根本没有时间看到沉降发生。承包商不得不使用144个新路桥结构将所有道路上现有桥梁进行替换。他们还必须在州际公路两边，用高容量车道和额外辅助车道加宽现有路面。所有这些都得在最短的时间内完成。

about 1m of consolidation settlement typically occurs when 10m high retaining walls or embankment are placed on top of saturated foundation soils. These soils require two years to complete consolidation settlement. Engineers who have be damaged. Repairing the damage caused by consolidation settlement takes time and money. Sometimes builders can feather in an overlay to make the surface even. In extreme cases the bridge approach has to be rebuilt.

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解决办法是使用叫做地基泡沫的一种特殊轻型材料。地基泡沫或者膨胀性聚苯乙烯（EPS）广泛用于包装和建筑工程之中。用可膨胀的聚苯乙烯树脂粒来生产膨胀性聚苯乙烯，这些聚苯乙烯树脂粒直径不到3毫米，含有充满起泡剂的微观组织，起泡剂可以膨胀为泡沫。通常的起泡剂是戊烷或丁烷，占珠粒重量的5%。

欧洲、日本和美国已经在轻型堤坝上使用了地基泡沫。大多数装置用于减少固结沉降，改善堤坝承载量，防止泥石崩塌或者抵抗地震。

在I-15工程开始施工前，工程师们在松软沉积区使用排水沟。这种防止沉降的做法仅仅维持了三个月。后来地基泡沫被用来建造轻型堤坝。施工人员在可能发生沉降的地区，铺设了大约10万立方米的地基泡沫。

密度在16千克/立方米到32千克/立方米之间的地基泡沫与堤坝材料2160千克/立方米相比，密度很小。所以，可以代替传统的陶制材料来保护公用设施的通道。这样容许州际公路旁边的地下公用管道设施在施工期间仍然可以用，不必进行代价高昂的中断、易位或者再定位。

I-15工程使用的地基泡沫方块高0.8米、宽1.2米、长4.9米。地基泡沫方块的底层铺设了0.2米的砂层。有些方块手工放入，在地势陡峭的堤坝，承包商则使用起重机提升地基泡沫方块，然后统一使用螺旋形锚安装到位。四个工人和一个领班每天能铺设200块。为了把方块凝结成混凝土板，要在顶部倾倒水泥。这样形成了粗糙的纹理，达到了表面间坚固的粘合。

工程中出现了一个问题，如果地基泡沫表面暴露在日光下超过照射时间，由于紫外线降解作用就会退色并起尘。工程师调查了暴露的地基泡沫样品，发现地基泡沫和浇灌的混凝土之间的接触面强度随紫外线强度和表面退化而降低。然而，如果地基泡沫方块在倒入混凝土前被强力清洗，就可以避免紫外线降解作用。

有关地基泡沫的另一问题就是，地基泡沫方块需要远离储存的

enough time can overbuild the embankment, making it 40 per cent higher than the bridge. Once the settlement has occurred, engineers remove the excess embankment.

But for the Interstate I-15 project in Salt Lake City, Utah, US engineers did not have time to allow settlement to occur. Contractors had to replace all the road's existing bridges with 144 new overpass structures. They also had to widen existing roadways with a high occupancy vehicle lane and an additional auxiliary lane on each side of the interstate. And it all had to be done in record time.

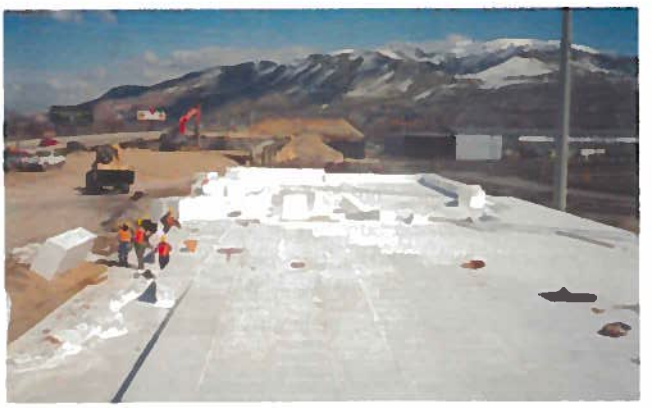
The solution: to use a special lightweight material called geofoam. Geofoam, or expanded polystyrene (EPS), is widely used for packaging and in building construction. Manufacturing of EPS uses expandable polystyrene resin beads that are less than 3mm in diameter and contain microscopic cells filled with a blowing agent to expand the foam. The usual blowing agents are pentanes or butanes and make up about 5 per cent of the bead weight.

Geofoam has been used for lightweight embankment applications in Europe, Japan and the US. Most installations involve reducing consolidation settlement, improving the embankment's bearing capacity, preventing landslides or earthquake proofing.

Before construction began on the I-15 engineers used drains in soft sediment areas. This process cut settlement duration time down to just three months. Geofoam was then used to create the lightweight embankments. Builders placed approximately 100,000 cubic metres of geofoam in settlement-prone areas.

大约10万立方米的地基泡沫用在了可能发生沉降的地区 Around 100,000 cubic metres of geofoam was used in settlement prone areas

州际公路旁边的地下公用管道设施在施工期间仍然可用



I-15是至今世界上唯一大规模使用地基泡沫的工程
The I-15: the single largest application of geofoam in the world to date

石油和溶解性溢出物，以及火和动物的袭击。在I-15工程中，负载分配平板、人行道和护墙板都防止溢出物和火。在堤坡放置地基泡沫方块时使用土工膜，这是一种聚氯乙烯、乙烯聚合物和聚氨酯的三重聚合物涂层。一种改进的阻燃性树脂也可用来防火，加入一些硼酸盐可以防止昆虫在材料上钻孔。

27公里的道路仅用了四年就完工了，花费了15亿美元（124亿人民币）。这是世界上唯一大规模使用地基泡沫的工程。这项工程赢得了2002年美国土木工程协会授予的土木工程杰出贡献奖。

地基泡沫堤坝和墙壁通常是传统机械修筑土墙成本的两到两倍半。额外费用非常值，提高了桥梁的寿命，减少了建造时间，免除了公用设施的损害或迁调费用。

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At 16 to 32 kg/cubic meter geofoam has a very low density when compared to embankment materials, which are 2160 kg/cubic metre. Because of this it can be used instead of traditional earthen materials to protect utility corridors. This allowed the underground utilities, which ran alongside the interstate, to remain in-service during construction without incurring the large costs associated with their interruption, replacement, and/or relocation.

The geofoam blocks used on the I-15 project were 0.8m high, 1.2m wide and 4.9m long. The bottom layer of geofoam blocks was placed on a 0.2 m of sand bedding. Some blocks were slid into place by hand. At steep embankments, contractors used a crane to lift the geofoam blocks. They were then fitted into place using corkscrew-type anchors. A crew of four workers and a foreman were able to place up to 200 blocks per day. To cement the blocks into place a concrete slab was poured on top. This creates a rough texture forming a strong adhesion bond between the surfaces.

One of the problems encountered on the project was that the geofoam surface was exposed to prolonged durations of sunlight. This led to discoloration and dusting of the surface due to ultraviolet degradation. Engineers examined samples of the exposed geofoam. They found that interface strengths between the geofoam and cast in-place concrete decrease with the level of UV exposure and surface degradation. However if the geofoam is power washed before the concrete is poured in then UV degradation can be avoided.

Another issue with geofoam is that it needs to be protected from potential petroleum and solvent spills, fire and animal attacks. On the I-15 project the load distribution slab, pavement section, and fascia panel wall offer protection against spills and fire. In places where the geofoam blocks are placed on a side slope, a geomembrane liner was used. This is a tri-polymer coating made of polyvinyl chloride, ethylene interpolymer alloy and polyurethane. A modified flame retardant resin was also used for fire protection; borate was added to prevent insects from boring into the material.

The 27km of road was completed in just four years and cost USD 1.5bn (RMB 12.4bn). This was the single largest application of geofoam in the world. The project won the 2002 Outstanding Civil Engineering Achievement award, presented by the American Society of Civil Engineers.

A geofoam embankment and wall usually cost between two and two and a half times that of traditional mechanically stabilised earth wall. The extra cost is worth it. The lifespan of the bridge is improved; construction time is reduced and utility damage or relocation costs avoided. ■

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