GLASS BEARING WALL

纯玻璃幕墙

GLASS BEARING WALLS – A CASE STUDY

玻璃承重墙案例研究

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关键词
1=结构玻璃 2=玻璃承重墙 3=建筑学 4=玻璃房屋
Keywords
1=structural glass 2=glass bearing walls 3=architecture 4=glass houses

图例1 玻璃承重墙 Figure 1 Load bearing glass wall.

摘要

在新墨西哥州州府圣达菲，一个住宅项目将不加任何支撑物的玻璃作为房屋主要的承重结构。这个项目旨在开发一种与建筑物无缝吻合的玻璃幕墙，同时研究这种玻璃承重墙对人造成的感官和心理影响。

这种玻璃承重墙高3.5米，长8.6米，能够承受钢制屋顶的重量。称之为结构玻璃是因为此系统融合了鳍片张力技术和钢制框架，可以支撑整个玻璃面。在这个项目中，玻璃幕墙没有任何连接件或紧固件暴露在外，所以可以最大限度地展示玻璃墙的美观效果。

现代房屋在整个20世纪的变革中，结构上基本没有变化。地板和房顶仍然由一系列的柱体支撑，而墙面没有支撑功能。将玻璃承重墙用于圣达菲的这一项目中挑战了人们对于传统房屋结构的看法。

此玻璃幕墙的规格，生产和安装都比较复杂，需要高度的协作性及灵活性。尤其当施工地点较远，需要与承包商和玻璃安装工人合作时，这些要求就更高。

这篇文章从建筑师的角度介绍了玻璃幕墙的设计以及完成过程，重点强调玻璃幕墙在美学及感知方面的作用。作者认为玻璃幕墙并不是什么奇怪的专业名词，建筑师常常提及。

简介

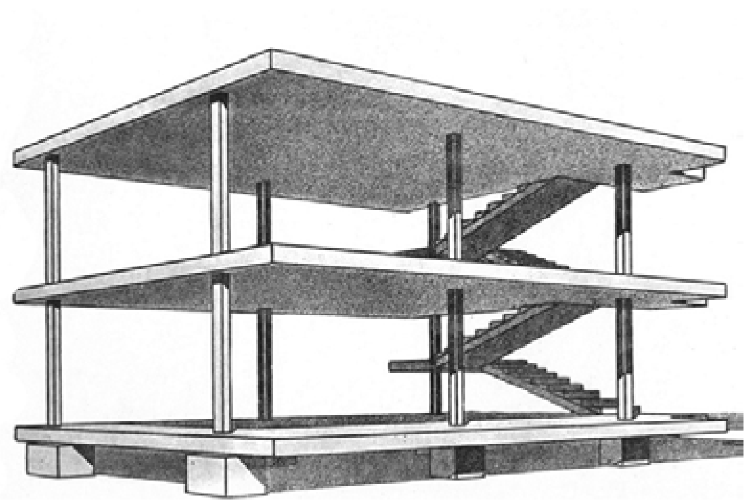
此住宅位于距圣达菲市北10公里的圣血山脉一个明显的位置。这里是一条狭长的风景带，由沙漠峡谷向山脚蔓延约50公里长。这个房子位于海拔2200米的山坡上，没有任何遮蔽物，

风也比较大。只有一条土路可以通往这里，这就给重型设备和玻璃的运输造成很大困难。

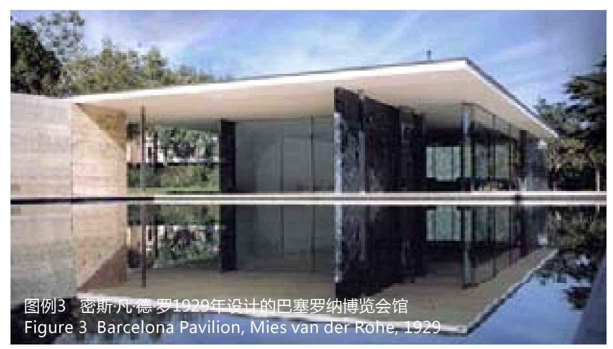
客户是当代艺术品收藏家，对现代玻璃房屋的美学价值及演变很感兴趣。建筑师使用承重玻璃的目的是一方面可以最大限度地在房屋内享受这里的风景，另一方面研究玻璃作为建筑物结构的作用。

玻璃房屋

整个20世纪，建筑师和工程师一直都对玻璃房屋怀有浓厚的兴趣。传统的建筑物重视遮风挡雨，与外界环境隔绝，玻璃房屋强调光线，透明度，开阔的空间以及屋内与屋外风景的融合。1914年柯布的“多米诺式住宅”使板柱结构房屋得以普及。这种房屋具备了以上提及的特点。没有了传统的墙面，柯布开创了房屋墙面自由设计的时代，玻璃可以在更大范围内使用，房间内的视野也变得更加开阔。这在以前都是不可能的。密斯.凡.德.罗的巴塞罗纳博览会馆、范斯沃思之家和菲利普.约翰逊1949年设计的“玻璃住宅”都表现了人们对于开阔空间的渴望。在这些所有示例房屋中，柱体仍然是房屋的主要部分，玻璃墙只是镶嵌在这些柱体之中。



图例2 1914年柯布的“多米诺式住宅”
Figure 2 Maison Domino, Le Corbusier, 1914



图例3 密斯.凡.德.罗1929年设计的巴塞罗纳博览会馆
Figure 3 Barcelona Pavilion, Mies van der Rohe, 1929

图例4 密斯.凡.德.罗1949年设计的范斯沃思之家
Figure 4 Farnsworth House, Mies van der Rohe, 1947

图例5 菲利普.约翰逊1949年设计的“玻璃住宅”
Figure 5 Glass House, Philip John- son, 1949

图例6 此项目的计划图
Figure 6 Overall Plan

1929年的巴塞罗纳博览会馆视觉上的感觉是纯净、通透。20世纪的很多建筑，以及我们这个项目都参考了它的设计。地板、玻璃墙、石墙以及看起来像悬浮在空中的屋顶都是建筑物的独立组成部分。会馆由八个轻型钢框支撑，玻璃墙和石墙可以随心镶嵌在这个框架之中。

钢柱非常细，不锈刚表面反光性好，这些迹象都表明钢柱有一天会消失，或者作用越来越小。接下来，墙板就会成为房屋的主要结构。这里有一个一直存在的疑问，即屋顶的重量是由厚厚的石墙支撑，还是由轻型钢柱支撑？结构上两者哪个更重要的问题至今没有答案，或许这个问题只有在未来才能解决。

如果说巴塞罗纳博览会馆是水平面和垂直面的融合，形式和空间的交织，那么范斯沃思之家和菲利普.约翰逊1949年设计的“玻璃住宅”则更明显带有“多米诺式住宅”的特点。在这两处建筑中，房顶由精心设计的钢架支撑，房屋四面都是玻璃墙。但是屋顶板和钢架的关系不太相同。范斯沃思之家的屋顶突出在钢架之外，而“玻璃住宅”的房顶在钢架范围内。由大块玻璃构成的房屋20世纪20年代在欧洲开始流行，到50年代在气候适宜的南加利福尼亚州流行。但是从20世纪中叶至今，玻璃在房屋建筑中如何使用仍然没有多大变化。虽然现今玻璃工艺学有了巨幅进步，但是这些新技术如何融入住宅建筑这一领域仍然进展缓慢。

构思

圣达菲的这个住宅是围绕着一系列平行的混凝土墙建造的。这些墙是这座住宅的支架。墙之间和四周安装着大块的落地玻璃幕墙，所以房子看起来很宽敞。

因为现在只是在对玻璃幕墙的性能进行试验，所以只在这座住宅最重要的位置，也就是客厅，安装玻璃幕墙。客厅正对着西面和北面的风景带，东西长度7.8米，南北长度10.2米。房间的南墙是40厘米厚的混凝土墙，东墙由钢架支撑，这些钢架隐藏在壁炉和烟囱架中。落地玻璃幕墙计划安装在房间的北面和西面，这样使房间的视野更加开阔。房间的北面和西面如果有可见的建筑结构，会影响房间的空间感。

玻璃承重系统

我们与Dewhurst Macfarlane密切合作，对几个玻璃承重墙的方案进行了研究。一种构想是房子的四个拐角处由L形状的玻璃圆柱支撑，然后用非承重玻璃作为墙面。另一种构想是四个拐角处由十字形玻璃支撑。材料选择方面，考虑使用夹胶玻璃，由两至三层的退火玻璃或钢化玻璃制成。经测试，退火玻璃即使破碎后仍有一些抗压力，但钢化玻璃破碎后毫无抗压力。关于这两种玻璃破碎后抗压力的大小已经过仔细研究，并发表在ATP Pavilion发展论文中。[1]

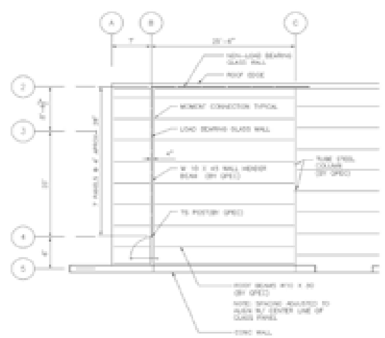
关于玻璃圆柱是应该隐藏在非承重玻璃墙中，还是采用双色镀膜的方法使其可见的问题，我们进行了讨论。由于客户崇尚现代艺术以及建筑物的空间感，所以最终决定将玻璃圆柱隐藏在非承重玻璃墙中。

一开始大家就一致认为制作一个模型和测试程序是很有必要的。对客户的项目事先进行评估非常重要，因为设计玻璃承重墙的工艺完全不同于传统的建筑工程，所以有必要在工程开始前制造模型并进行测试。测试过程中也应该让当地的玻璃幕墙安装人员参与进来，确保他们能够达到工程要求的安装水平。虽然这项工程资金预算充足，工作人员还是正在努力使玻璃制作工艺变得简单，价格变得低廉。

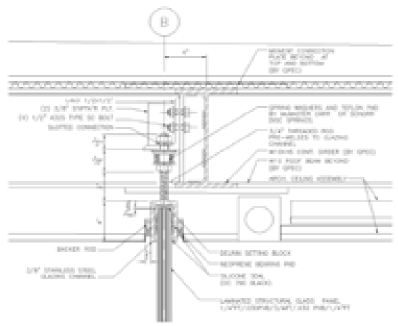
通过对四角支柱的进一步研究发现，玻璃墙与屋顶和地面的连接如果过于复杂，那么玻璃墙的制造和安装也会变得复杂。有人提议采用凸轮或刃角连接，以使负荷均匀地分布到夹胶玻璃的每一层。如果负荷全部由四角的支柱支撑，并且不使用多层玻璃制成的夹胶玻璃，那么房屋的安全系数就会降低。

玻璃幕墙的设计

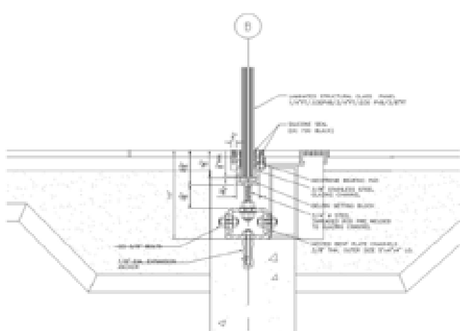
房间的西墙是由多块玻璃连接在一起的玻璃幕墙。8.6米（房间的长度



图例7 房屋的结构图
Figure 7 Plan of Structure



图例8 玻璃与屋顶连接件详图
Figure 8 Head Detail.



图例9 玻璃与地面连接件详图
Figure 9 Sill Detail

图例10 铁槽详图
Figure 10 Shoe Detail

是10.2米，由于这面墙有门，所以长度减短）的长度使玻璃幕墙的承重面积较大。虽然多层玻璃幕墙稍显冗余，但可以防止房子垮塌。玻璃幕墙的上方有一条钢梁，这样使玻璃幕墙与屋顶的连接更加简单，屋顶看起来也比较简约。同时，屋顶上安装的悬臂装置可以降低钢梁因受力过大而扭曲变形的程度。玻璃始终会承重，所以玻璃的柔韧性在这里显得尤为重要。

我们的目标是墙面只有玻璃构成，所以玻璃幕墙顶端和底部的连接点都被隐藏在屋顶和地板内。按照巴塞罗纳博览会馆的设计理念，任何连接件、支柱和紧固件都必须隐藏起来，这样玻璃幕墙看起来才是建筑物独立的一部分。

最新研究表明，房顶的固定荷载并没有超出要求，不需要额外的支撑物，所以连接件就不必承受张力，而只需要承受压力。这就大大简化了连接件的设计。Dewhurst Macfarlane与当地建筑工程师合作，研究如何使玻璃幕墙与屋顶设计协调一致。例如：屋顶隔板要足够坚硬以确保水平负荷不会转移到玻璃幕墙上。

此项目对选择几块玻璃板也进行了研究。2米宽的玻璃板较为容易连接在一起，所以最少需要5块玻璃板。考虑到制作方便以及美观，经研究最终决定使用7块约1.2米宽的玻璃板连接在一起。玻璃板之间间隔约1厘米，使用无色的硅树脂填充空隙。

玻璃由三层组成。中间是0.75英寸厚的钢化玻璃，两面各有一层0.25英寸厚的钢化玻璃，各层中间是0.06英寸厚的聚乙烯醇缩丁醛隔层。7块玻璃板连接在一起使整个玻璃幕墙制作工艺比较复杂。中间的0.75英寸厚的钢化玻璃层足以承受三层玻璃应该承受的压力。两面的0.25英寸厚的钢化玻璃层不必承受负荷，所以在设计时就比中间一层短四分之一。所有的负荷都是通过中间一层转移到地面的。两面的0.25英寸厚的钢化玻璃层在与中间一层叠加的过程中，允许出现上下0.125英寸的滑动，这就大大简化了玻璃板和连接点的制作工艺。鉴于中间一层非常重要，这层玻璃要特别经过热浸处理。大多数玻璃生产商不愿生产经热浸处理的玻璃，所以我们的供应商仅限两家。3.5米高的玻璃，客户所能接受的最大挠度是3.5厘米。正常的挠度是从L/120 到L/150。

此项目对生产一种绝缘的玻璃承重墙也进行了研究。只要玻璃的一面比另一面稍长，承重稍大，另一面就会形成空洞而达到绝缘的目的。但是，定位块和胶水会在玻璃表面形成黑色带状痕迹，影响玻璃墙的美观。如果有无色的定位块和密封剂我们一定会认真考虑使用。如果能生产绝缘的玻璃承重墙，这个项目的难度将会大大增加，玻璃幕墙的美观程度也会受到影响。怎样研制出一种不会因定位块和密封剂而影响美观的绝缘玻璃幕墙将会是未来研究的重点。

⊙玻璃墙与屋顶及地面的连接件安装

玻璃墙的上下两端都镶嵌在很深的U形铁槽内。因为铁槽里面有橡胶定位块，所以玻璃墙可以紧紧地镶嵌在铁槽内。想要购买到合适尺寸的铁槽基本不可能，所以与玻璃墙宽度相同的铁槽是由两个特制的半槽焊接在一起制成的。每个铁槽左右两端四分之一处各有一个螺纹杆。安装螺纹杆一方面可以将玻璃墙承受的负荷转移到屋顶钢板或地面，另一方面可以使铁槽保持水平，确保玻璃墙中间一层的底部受重均匀。

为了确保屋顶重量均匀分配到玻璃墙上，每个玻璃墙与屋顶的连接紧

图例11 屋顶结构　Figure 11 Roof Framing

图例12 铁槽结构　Figure 12 Top Shoe Detai

固件上都安装有弹簧垫圈。螺纹杆上的螺母大小一样，所以弹簧垫圈的高度都是相同的。玻璃墙安装数月后，如果弹簧垫圈的高度没有变化，说明玻璃墙承重均匀。另外，如果屋顶重量异常或一块玻璃板破碎，弹簧垫圈可以帮助将屋顶的重量重新分配到剩余的玻璃板上。

⊙测试和安装

研究人员对一块符合尺寸的玻璃板和几块稍小的玻璃板进行了测试。符合尺寸的玻璃板不仅要承受不断增加的轴向负荷，还要承受用来模拟不同方向风力的横向负荷。经实验证实，小玻璃板无法承受这些负荷。正如之前告诉客户的那样，设计以及执行测试程序既耗时又费钱。而要开发出一个更为简单的测试系统需要很长时间以及大量努力，这些都应该让客户知道并使其有所准备。

在安装玻璃墙之前，应该与承包商协商决定施工中各个程序的顺序。在可行范围内，玻璃越晚运到施工地点越好，以减小因其它施工而破坏玻璃的可能性。钢板屋顶基本上要吊升至应有高度并用支柱支撑。起重机将玻璃墙吊至安装位置之前，在地面上将铁槽安装在玻璃板上。安装玻璃墙时，应逐步将玻璃与屋顶的连接处紧固，慢慢地将负荷均匀转移到玻璃墙上。2.6米高的屋顶悬臂应在玻璃墙之后安装，所以安装悬臂时应特别注意保护玻璃。准备工作如果充分仔细，玻璃墙在一天之内就能安装完毕。

⊙概要

玻璃幕墙房屋的视觉效果很好，很吸引人，远观像一副画。大面积的屋顶向玻璃墙外延伸，仿佛给这副画镶框，参观者的视线也被吸引过来。玻璃是透明的，屋顶仿佛没有任何支撑物而悬浮在空中。一旦意识到屋顶完全是由玻璃墙支撑着，参观者都会又惊讶又好奇。透明建筑物可以使屋内和屋外风景融为一体，而玻璃幕墙是人们在建筑物透明化的道路上迈出的重要一步。玻璃幕墙的使用模糊了工程学和美学的界限，扩大了建筑的概念。

[1] “设计规划世界上最大的玻璃结构建筑物” F.Bos et al, GPD 2005

图例13 安装玻璃板
Figure 13 Panel Installation

图例14 玻璃板安装完毕后　Figure 14 Completed Installation

Abstract

Glass is used as an unbraced, primary load bearing element in a residential project in Santa Fe, New Mexico. The intent was to create a pure wall of glass that would seamlessly integrate with the architecture, and to explore the perceptual and psychological impact of a load bearing glass wall.

The glass bearing wall measures 3.5m high by 8.6 m in length and transfers the loads from a steel framed roof into a concrete foundation. What is typically referred to as structural glass is a system incorporating fins, tension systems and/or steel frames to support a glass facade. In this project there are no exposed connections or fasteners so the sheer, crystalline nature of the glass can be fully appreciated.

Throughout the evolution of the 20th century modern house the structural system has for the most part remained unchanged from the conventional model of flat floor and roof plates supported by a grid of columns, with non-load bearing facades. Load bearing glass was used in the Santa Fe project to challenge the preconceptions of what constitutes a structural element and make the viewer aware of how we take conventional structure for granted.

The specification, fabrication and installation of this glass bearing wall system required a high degree of collaboration and flexibility, particularly given the remote site and desire to work with local contractors and glass installers.

This presentation describes the process of design and realization from the architect's point of view, with an emphasis on the aesthetic and perceptual aspects of the load bearing glass system. The author proposes that load bearing glass does not have to be an exotic specialty item and can be readily used as a highly expressive part of the architect's vocabulary.

Introduction

The project is located on a dramatic site in the Sangre de Christo mountains about 10km north of Santa Fe. The panoramic vistas extend across the desert valley towards mountain ranges about 50 km to the east and north. The site is an exposed mountain hillside at 2200 m altitude with potentially high winds. Access is via a difficult dirt road, posing significant challenges for access of heavy equipment and the delivery of the glass.

The clients are collectors of contemporary art who are particularly interested in the aesthetics and evolution of the modern glass house. Load bearing glass was proposed by the architect as a way to take greatest advantage of the vistas, and to explore the ability of glass to simultaneously serve as an architectural enclosure and a structural element.

The Glass House

The concept of the glass house has been of great interest to architects and engineers throughout the 20th century. Where traditional architecture emphasizes enclosure, shelter and protection against the world outside, the glass house speaks to the importance of light, transparency, the flow of open spaces, and a strong connection between interior and exterior. These qualities were made possible by the development of the slab and column construction system popularized by Le Corbusier in his Domino House of 1914. By eliminating traditional bearing walls he opened the door for the "free plan" and the "free façade", and thus the possibility of significant expanses of glass and a degree of openness that was not previously possible. Iconic structures such as Mies van der Rohe's Barcelona Pavilion and Farnsworth House and Philip Johnson's Glass House are highly refined expressions of this quest for openness. In all of these examples the structural columns were clearly expressed and the glass walls were conceived as infill elements that were secondary to the structural system.

The sculptural clarity of the Barcelona Pavilion of 1929 was an important reference point for much of 20th century design and for this project. The ground plane, the glass and stone walls, and the floating roof plane are masterfully configured to read as pure, independent elements. The design includes eight slender steel columns which allow the glass and stone wall planes to be located as desired in this "free plan". The thinness of the columns and their highly reflective stainless steel surface suggests that they were intended to recede if not disappear. This has the effect of making the wall planes the dominant elements. There is an inherent ambiguity here - is the weight of the roof being borne by the thick stone walls or the slender columns? The issue of structural primacy is left unresolved, perhaps to pose this as a problem to be solved in the future.

Where the Barcelona Pavilion is about the poetic composition of horizontal and vertical planes and the interweaving of form and space, the Farnsworth House of 1947 and Philip Johnson's Glass House of 1949 are more direct expressions of the Domino type. Both have strongly defined roof planes supported by classically composed columns, and both houses are glazed on all four sides. The relation of the roof plane to the columns is very different, with the roof extending out into space at the Farnsworth, but staying bounded by the columns at the Glass House. Houses with large areas of glass quickly became commonplace in the 1920's in Europe and particularly in southern California in the 1950's where the climate was so advantageous, but the ways that glass is conceived and used to this day have not changed significantly since mid century. Despite the recent exponential advances in glass technology, these developments have been slow to find their way into the realm of residential design.

Concept

The Santa Fe residence is organized around a series of parallel concrete walls. These walls serve as an armature around which the house is assembled. Spaces are created by using large expanses of floor-to-ceiling glazing around and between the

FROM THE EARLIEST DISCUSSIONS IT WAS AGREED THAT A THOROUGH MOCKUP AND TESTING PROGRAM WOULD BE A NECESSARY PART OF THE PROCESS

concrete walls.

Due to the experimental nature of the glass design it was decided to limit the glass bearing system to the most important location in the house, the Living Room which is oriented towards the big views to the west and north. The space measures 7.8 m east-west by 10.2 m north-south. The south wall is 40 cm thick concrete and the east side has steel framing concealed inside a fireplace chimney enclosure. Floor to ceiling glass was planned for the north and west sides of the space in order to create an expansive glass room. It was important to have no visible structure in this corner in order to create an experience of pure space, form and materials.

Glass Bearing System

Working closely with Dewhurst Macfarlane, several options for a load bearing glass system were studied. The first concept was a load bearing L shaped glass column located in the corner, in plane with non-bearing glass panels that would enclose the space. An alternative configuration was a cruciform column. Options of two or three layers of laminated glass were considered, and the issue of annealed or tempered glass was examined. Annealed glass was preferred because a cracked ply could retain some strength as part of the laminated assembly, whereas a tempered glass ply would have no residual strength. This desirability of an identifiable "crumbling" failure mode has been very well studied and presented in the development of the ATP Pavilion. [1]

We discussed whether this columnar element should be made to disappear into the non-bearing glass, or whether it would be psychologically reassuring to make it visible, perhaps by means of a dichroic coating. The clients were interested in issues of space and perception in contemporary art and architecture so it was agreed to make the load bearing column blend into the glass walls.

From the earliest discussions it was agreed that a thorough mockup and testing program would be a necessary part of the process. It was important to appraise the client early on that it would be necessary to build full size mockups and do extensive testing, and that the process of designing load bearing glass would be very different from traditional structural engineering. The local glass installers were brought into the process at this stage to ensure that they were willing and able to meet all the project requirements. While the budget for the project was generous, there was an ongoing effort to develop details that would be relatively easy to fabricate and cost effective.

Further research into the corner column concept revealed complex connection issues that would make fabrication and installation difficult. A cam/bezel connection was proposed in order to evenly distribute the load into each ply of a multi-ply bearing element. The concentrated load on a corner column and the absence of any redundancy would have required a very high safety factor.

Bearing Wall Development

It was decided to make the longer west wall into a multi-panel bearing wall. The 8.6 m length (less then the overall room size of 10.2 m due to a door) allowed the load to be distributed over a large bearing area. The multiple panels provided redundancy in case of failure. A continuous steel beam was located above the bearing wall in order to simplify the roof framing and provide an easy place to make the connection details at the head. There is a cantilevered roof overhang on the exterior side of this exposure which reduces the torsion on this beam. The glass would work in compression so the controlling characteristics would be its flexibility and slenderness.

The goal was to create a pure plane of glass so we needed to conceal all connection hardware at the top and bottom of the bearing wall by burying it in the ceiling and floor. In the spirit of the Barcelona Pavilion, the glass wall wanted to be a completely independent, sculptural element, without visible connections, bracing or stiffeners.

Further study determined that the dead load of the roof was sufficient that there would be no requirement to resist uplift, thereby eliminating the need for any type of connection that would resist tensile forces. Making the connections to take purely compressive loads allowed the connection details to be greatly simplified. Throughout this process Dewhurst Macfarlane worked closely with the local structural engineers to coordinate the glass wall with the design of the roof, for example to ensure that the roof diaphragm was stiff enough that lateral loads would not be introduced into the glass bearing wall.

Options for the number of panels were studied. Lamination could be easily done up to 2 m in width, so a minimum of five panels would be required. The final selection was to use seven panels each approximately 1.2 m wide. This was based on ease of fabrication and visual appearance.The joints between panels were approximately 1 cm wide and were filled with clear silicone. The decision was made to use three ply glass panels with a 3/4" inch fully tempered ply in the center, 1/4" fully tempered plies on each side, and 0.06" PVB interlayers. The use of seven panels

图例15 室内视野 Figure 15 interior looking out

created a high degree of redundancy, and the center 3/4" ply had enough compressive strength to meet the safety factor requirement of 3. Because the outer 1/4" plies were not needed for load bearing they were designed to be 1/4" shorter than the center ply, thereby ensuring that all the load was transmitted through the center ply. The 1/4" was determined to be adequate to compensate for up to 1/8" of slippage during the lamination process. This greatly simplified the fabrication of the panels and the connection details. Due to the reliance on only the center ply, heat soaking was specified for these pieces of glass. Most glass manufacturers were not eager to provide heat soaked glass so this narrowed the choice to two vendors.

A maximum deflection of L/100, or 3.5 cm over a 3.5 m height, was considered the maximum that the client would find acceptable, and a deflection of between L/120 to L/150 was the target range.

The option of creating an insulated load bearing glass was studied. This would have been accomplished by making one of the two glass faces longer and load bearing, and using the other to create the insulating cavity. However, the spacer bars and adhesives would have created black stripes that would have significantly changed the appearance of the glass wall. If a system of clear spacer bars and sealants was available it would have been seriously considered. Creating load bearing insulated glass would have added a significant degree of complexity to the project and compromised the aesthetics. In the future it would be very attractive to find techniques to create insulated glass without the visual drawbacks of the spacer bars and sealants.

图例16 室外视野 Figure 16 Exterior

Head and Sill Connection

A deep U-shaped shoe that ran the full width of the glass panels was developed for the head and sill connections. The shoes were designed to fit snugly against the glass panels with neoprene spacers on each side. Purchasing a shoe of the correct dimensions was not possible so a shoe of precisely the right width was fabricated by using two steel angles that were machined and fixed together. Each shoe has two threaded rods, located at the quarter points, to transmit the load into the roof steel or foundation and allow precise leveling of the shoes to ensure very even load distribution across the end surfaces of the 3/4" ply.

To ensure the even distribution of the roof load a stack of spring washers were used at each of the head connections. A system of nuts on the threaded rods allowed the height of the stack of spring washers to be carefully equalized. The exact height of this stack could then be checked several months after installation to ensure that the panels were still being uniformly loaded. Additionally, in the event of abnormal loading of the roof or the loss of a panel the spring washers would assist in redistributing the load.

Testing & Installation

A full sized glass panel and a series of smaller test panels were fabricated for testing. The full panel was subjected to a series of increasing axial loads while a variety of lateral loads were applied so simulate various wind loads. The smaller samples were tested to failure.

As previously indicated to the client, the design and execution of the testing procedure was time consuming and had a significant cost. This reinforced the importance of thoroughly preparing the client for the time and effort required to develop even a relatively simple system such as this one.

A number of construction sequence issues were reviewed with the contractor before the installation was started. The glass was planned to arrive as late as feasible to reduce the possibility of damage by other construction. The roof steel was to be erected at or slightly below its final elevation and held in place with shoring. The shoes would be installed onto the glass panels in the field just prior to craning the panels into place. When the glass panels were installed they would then be very gradually tightened up against the roof connections to slowly and evenly transfer the load onto the glass. The 2.6 m roof cantilever could not be installed until after the glass was in place so particular attention was paid to the protection of the installed glass.The preparation was thorough and complete and the glass installation was completed in less than a day.

Summary

The architectural space formed by the load bearing glass wall is visually remarkable and psychologically very intriguing. The large area of roof which cantilevers out past the glass wall is very dramatic in the way it both frames the landscape and pulls the viewer out towards it. The hovering roof plane provides an unusual sense of shelter because there is clearly no visible means of support. Once the viewer is made aware that the pure glass wall is holding up the roof the perception changes again to one of surprise and curiosity.

Glass bearing walls represent an important step in the quest for truly transparent structure that allows a seamless flow between interior and exterior. The use of glass bearing walls is an exciting opportunity to blur the distinction between engineering and aesthetics and thereby expand the vocabulary of architecture.

[1] Designing and Planning the World's Biggest Experimental Glass Structure, F. Bos et al, GPD 2005

致谢

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